RESEARCH SERIES NUMBER 79
October 2018

# THE ECONOMIC AND ENVIRONMENTAL IMPACTS OF INCREASING THE IRISH CARBON TAX

KELLY C DE BRUIN AND AYKUT MERT YAKUT


ESRI ECONOMIC & SOCIAL RESEARCH INSTITUTE

# THE ECONOMIC AND ENVIRONMENTAL IMPACTS OF INCREASING THE IRISH CARBON TAX

Kelly de Bruin

Aykut Mert Yakut

**October 2018**

**RESEARCH SERIES**

**NUMBER 79**

Available to download from www.esri.ie



ISBN 978-0-7070-0470-9

DOI https://doi.org/10.26504/rs79

# ABOUT THE ESRI

The mission of the Economic and Social Research Institute is to advance evidence-based policymaking that supports economic sustainability and social progress in Ireland. ESRI researchers apply the highest standards of academic excellence to challenges facing policymakers, focusing on 12 areas of critical importance to 21st-century Ireland.

The Institute was founded in 1960 by a group of senior civil servants led by
Dr T.K. Whitaker, who identified the need for independent and in-depth research analysis to provide a robust evidence base for policymaking in Ireland.

Since then, the Institute has remained committed to independent research and its work is free of any expressed ideology or political position. The Institute publishes all research reaching the appropriate academic standard, irrespective of its findings or who funds the research.

The quality of its research output is guaranteed by a rigorous peer review process. ESRI researchers are experts in their fields and are committed to producing work that meets the highest academic standards and practices.

The work of the Institute is disseminated widely in books, journal articles and reports. ESRI publications are available to download, free of charge, from its website. Additionally, ESRI staff communicates research findings at regular conferences and seminars.

The ESRI is a company limited by guarantee, answerable to its members and governed by a Council, comprising 14 members who represent a cross-section of ESRI members from academia, civil services, state agencies, businesses and civil society. The Institute receives an annual grant-in-aid from the Department of Public Expenditure and Reform to support the scientific and public interest elements of the Institute's activities; the grant accounted for an average of 30 per cent of the Institute's income over the lifetime of the last Research Strategy. The remaining funding comes from research programmes supported by government departments and agencies, public bodies and competitive research programmes.

Further information is available at www.esri.ie

# THE AUTHORS

Kelly de Bruin is a Research Officer at the Economic and Social Research Institute (ESRI). Aykut Mert Yakut is a Postdoctoral Research Fellow at the Economic and Social Research Institute (ESRI).

# ACKNOWLEDGEMENTS

The research carried out in this report was funded by the Department of Finance and is part of an ongoing modelling project funded by the Department of Communications, Climate Action and Environment (DCCAE). The authors would like to thank Edgar Morgenroth, John Curtis, Adele Bergin, Kieran McQuinn, Martina Lawless, Sean Lyons and Valentin Bertsch at the ESRI, as well as two anonymous reviewers for their valuable inputs. We would also like to thank Mitra Kami Delivand, James Glynn and Brian Ó Gallachóir at UCC and Emer Dennehy at SEAI for their inputs.

# CONTENTS

Executive Summary ........ i

Chapter 1: Introduction ........ 1

Chapter 2: Literature review ........ 4

Chapter 3: Methodology ........ 7

3.1 The Energy Social Accounting Matrix ........ 7

3.2 Structure of the Irish ESAM ........ 9

3.2.1 Activities and commodities ........ 9

3.2.2 Energy disaggregation ........ 10

3.2.3 Households’ disaggregation ........ 12

3.3 Methodology of price multipliers ........ 12

3.4 Post-multiplier analysis ........ 13

Chapter 4: Results ........ 17

4.1 Current Irish carbon tax policy ........ 17

4.2 Carbon commodity sales tax ........ 18

4.3 Carbon commodity purchaser prices ........ 19

4.4 Producer prices ........ 20

4.5 Consumer prices ........ 23

4.6 Monetary cost for households ........ 26

4.7 Emission reductions ........ 29

Chapter 5: Conclusions ........ 34

Appendix A: Aggregated version of the Irish SAM ........ 36

Appendix B: Lists of activities and commodities ........ 37

Appendix C: Price multiplier methodology ........ 40

Appendix D: Additional tables ........ 45

Appendix E: Nested structures of consumption and production ........ 51

References ........ 55

## LIST OF TABLES

Table 4.1 Irish carbon tax levied for various fuels in 2014 .......... 18
Table 4.2 Sales tax rates by carbon commodities .......... 19
Table 4.3 Changes in purchaser prices of carbon commodities (per cent) .......... 20
Table 4.4 Changes in producer prices of selected activities (per cent) .......... 21
Table 4.5 Export shares of commodities (per cent) .......... 22
Table 4.6 Changes in consumer price index (per cent) .......... 23
Table 4.7 Budget shares of energy commodities by household (per cent) .......... 25
Table 4.8 Changes in specific consumer price indices (per cent) .......... 26
Table 4.9 Weekly monetary cost by household .......... 27
Table 4.10 Weekly monetary cost by components .......... 28
Table 4.11 Cost-to-income ratio (per cent) .......... 29
Table 4.12 Changes in selected activity-based emissions (per cent) .......... 31
Table 4.13 Changes in household emissions (per cent) .......... 33
Table B.1 Activities by groups .......... 37
Table B.2 Commodities .......... 39
Table C.1 Artificial SAM (2 activities × 3 commodities) .......... 40
Table C.2 Artificial SAM in coefficients (2 activities × 3 commodities) .......... 41
Table D.1 Changes in purchaser prices (per cent) .......... 45
Table D.2 Changes in producer prices (per cent) .......... 47
Table D.3 Changes in activity-based emissions (per cent) .......... 49

## LIST OF FIGURES

Figure E.1 Composite private consumption .......... 51
Figure E.2 Production, except electricity production .......... 52
Figure E.3 Fuel consumption by group of activities .......... 53
Figure E.4 Electricity production .......... 54

# ABBREVIATIONS

| | |
|---|---|
| CES | Constant Elasticity of Substitution |
| CGE | Computable General Equilibrium |
| CPI | Consumer Price Index |
| CSO | Central Statistics Office |
| EA19 | Euro Area |
| EGS | Electricity and Gas Supply |
| EPA | Environmental Protection Agency |
| ESAM | Energy Social Accounting Matrix |
| ETS | Emissions Trading System |
| GHG | Greenhouse Gas |
| I3E | Ireland Environment Energy Economy |
| INDCs | Intended Nationally Determined Contribution |
| IO | Input–Output |
| ktoe | kilotonnes of oil equivalent |
| MQE | Mining, Quarrying and Extraction |
| PET | Petroleum, Furniture and Other Manufacturing |
| SAM | Social Accounting Matrix |
| SEAI | Sustainable Energy Authority of Ireland |
| SUT | Supply and Use Table |

# EXECUTIVE SUMMARY

This study investigates the economic and environmental impacts of increasing the current carbon tax in Ireland from €20 per tonne of $CO_2$ to €25, €30, €35 and €40. For this purpose, an Energy Social Accounting Matrix (ESAM) is developed for Ireland with 33 activities, 39 commodities, and ten household groups based on disposable income. The ESAM reproduces the structure of the Irish economy including production sectors, households and the government and quantifies the nature of all existing economic transactions among the diverse economic agents. Furthermore, the ESAM includes the flows of energy and emissions, creating a framework that can examine how money as well as energy and emissions flows between production sectors, households and the government. In this way the carbon content of different products and different households' consumption is estimated.

The current carbon tax in Ireland stands at €20 per tonne of carbon and is levied to incentivise households and producers to reduce their use of carbon-intensive goods. The carbon tax is relatively low, however, and constitutes just 1.9 per cent of total taxes levied on commodities in Ireland. Carbon tax accounts for only 7.6 per cent of total excise duties levied on petrol and 14 per cent of all excise duties on diesel.

Our results reveal that increases in the carbon tax affect the prices of diesel and petrol the most. A €5 increase will increase the prices of carbon commodities by on average 0.8 per cent, and a doubling of the carbon tax to €40 per tonne of $CO_2$ will increase the prices of carbon commodities by on average 3.4 per cent. The diesel price is expected to increase the most due to an increase in the carbon tax, whereby a €25 tax would result in a 1.7 per cent increase in diesel prices. A €40 tax would result in a 7 per cent increase in diesel prices. Putting this into context, it can be noted that in 2018 alone consumers have faced much greater fluctuations in diesel prices. Consumers are accustomed to relatively large fluctuations in fuel prices and may not react to increases in prices, assuming prices will fall again. This makes it extremely important to communicate a clear commitment to an increasing carbon tax by the government.

To gain a better understanding of which production sectors are most vulnerable to increases in the carbon tax, we estimate the impacts of a carbon tax increase on production costs across sectors. Overall, the impacts of increasing the carbon tax by €5 on total production costs of sectors are extremely small. Even for larger increases of the carbon tax, the impacts remain low; for example, a doubling of the carbon tax will increase production costs by at most 1.4 per cent. Our results show that the natural gas supply sector and the transportation sectors are impacted the most. Impacts on other sectors are small. Notably, the production sectors that drive Irish exports are relatively insensitive to a carbon tax increase, suggesting that an increase in the current carbon tax will not have significant impacts on the international competitiveness of Irish exports.

An important issue concerning the implementation of a carbon tax is its distributional impact across different household types. We therefore examine the impacts of a carbon tax increase across income deciles. According to our estimates, the impact on the Consumer Price Indexes (CPIs) of the different households is virtually uniform, whereby a €20 increase in the carbon tax leads to the CPI of all households increasing by approximately 0.5 per cent and a €5 increase leads to a 0.1 per cent increase of CPI.

To investigate the potential implication of a carbon tax increase for fuel poverty, we also examine the changes in households' energy CPI. We find that energy CPI increases more among richer households due to a carbon tax increase. While the poorest households face a 2.9% (0.7%) increase in energy CPI for a €20 (€5) increase in carbon tax, the richest households face a 4.5% (1.1%) increase. Heating CPI, on the other hand, shows slightly higher increases for the poorest households (1.1%) compared to the richest (0.9%) for a €20 increase.

In monetary terms a €20 (€5) increase in carbon tax would cost the poorest households €1.87 (€0.45) a week and the richest €9.63 (€2.30) a week. When these costs are expressed in terms of income, they are found to be regressive, i.e. the poorest households will lose a higher share of their income (0.67%) compared to the richest (0.28%).

Examining the potential impacts of an increase in carbon tax on emissions reduction in Ireland, we tentatively estimate that a doubling of the carbon tax will result in less than a 5% decrease in GHG emissions. For a €5 increase, our results show that economy-wide emissions are reduced by 1.2%. This indicates a strong need for a more stringent carbon tax policy in combination with other policy levers to ensure a transition towards a low-carbon economy.

It is important to interpret these results with caution given the static methodology applied here. The impacts presented in this report should be seen as short-term impacts, as no dynamics are included in the agents' decision making. A Computable General Equilibrium (CGE) model could give more accurate insights into specifically the long-term impacts of climate change policies. Currently such a model, namely the Ireland Environment Energy Economy (I3E) model, is being developed by the ESRI.

# CHAPTER 1

# Introduction

The impacts of carbon emissions on our climatic system have long been recognised by the international academic community. Human-induced climate change is estimated to have increased atmospheric temperatures by over 0.8°C to date compared to pre-industrial levels (IPCC, 2014). Climate change involves, in addition to increases in temperature, more variability in temperature and precipitation, increased occurrences of extreme weather events and sea-level rise. The impacts of these climatic changes on societies and economies are uncertain but are expected to be very significant: at a global level economic damage of approximately 2% of GDP per year is estimated for a temperature increase of 2.5°C (IPCC, 2014). In the case of Ireland, impacts over the coming decades could include among others impacts of sea-level rise on coastal areas, more intense storms and rainfall events, increased flooding, summer water shortages, increased risks of new pests and diseases, and adverse impacts on water quality (Desmond et al., 2017). Impacts over longer periods of time and higher levels of climate change are highly uncertain and could result in abrupt weather change and climatic tipping points.

The expected impacts of climate change have led to global recognition of the need to limit climate change. Through the United Nations Framework Convention on Climate Change (UNFCCC), countries have negotiated in recent decades to combine efforts to decrease greenhouse gas (GHG) emissions. In 2015, the Paris Agreement was adopted and to date it has been ratified by 194 states and the European Union, though the US has given notice to withdraw from the agreement. Within the Paris Agreement, members of the convention voluntary submit their national emission targets through Intended Nationally Determined Contributions (INDCs), which are to be updated at five-year intervals. The EU has been to the forefront of international efforts to reduce GHG emissions and was the first major economy to submit its INDCs. The main elements of the EU INDCs are summarised in the EU 2030 climate and energy framework, which defines three key targets to be reached by 2030: at least 40% GHG emission reduction (compared to 1990 levels), at least 27% share of renewable energy, and at least 27% improvement in energy efficiency. The EU has also defined a longer-term perspective on climate and energy policy for 2050, which decreases emissions by 80–95% of 1990 levels.

To achieve these targets at the least cost, the EU has implemented a cap and trade system, namely the EU Emissions Trading System (ETS). It operates in all 28 EU countries as well as in Liechtenstein and Norway covering 45% of EU GHG emissions. In this system, heavy energy-using installations (power stations and industrial plants) and airlines in the EU have to buy emission allowances, which are auctioned based on the overall EU emissions cap. Each year companies need to surrender allowances to cover their emissions or face heavy fines. Companies can trade emissions throughout the EU ensuring that emissions are cut where it costs the least to do so. The cap is set to decrease emissions from the ETS sectors by 21% in 2020 (compared to 2005) and by 43% in 2030. Emissions in non-ETS sectors will need to be cut by 30% (compared to 2005), where the overall EU goal is translated into the individual binding target for the Member States based on the Effort Sharing Decision. The decision lays out annual emission allocations to Member States based on relative wealth. The Effort Sharing Regulation further sets binding annual targets for Member States from 2021 to 2030. Overall, the EU has shown a strong commitment to climate policy in the long-run, with increasingly stringent targets over time.

The non-ETS reduction target for Ireland is, along with that of Denmark and Luxembourg, the most challenging target in the EU, namely a 20% reduction compared to 2005 levels by 2020. Ireland also faces a renewable energy target of 16% of final energy use and 10% of energy use in transport. These targets are legally binding and should Ireland not meet its targets, it will face fines. Recent estimates by the Environmental Protection Agency (EPA) project that GHG emissions are to increase in most sectors in Ireland given the strong economic growth and the expansion of the agricultural sector (EPA, 2018). These estimates show that, at best, Ireland will achieve a 1% reduction of emissions by 2020, in contrast to its binding target of 20%. Though steps have been taken to limit GHG emissions in Ireland through a carbon tax, it is evident that there is a strong need to improve climate policy in Ireland to reach its 2020 targets in order to avoid facing EU-level fines and to contribute to the transition to a low-carbon global economy.

It is imperative that appropriate energy policies including a carbon tax pathway be designed to ensure a smooth and least-cost transition to a low-carbon economy. Research is needed to increase our understanding of the macroeconomic implications of various policies and to investigate how different production sectors and household groups are affected, in order to help to identify winners and losers of potential policies and to assist in the design and implementation of sound energy policies. Furthermore, there is a need to understand how climate policies may affect emissions through the behaviour of firms and households to ensure that policies will result in the needed emission reductions.

This report aims to shed light on the impacts of increasing the Irish carbon tax on both the economy, in terms of increased production costs across industries and increased consumption costs across household types, and the level of emissions through emission reduction responses to increased prices. For this analysis, an Energy Social Accounting Matrix (ESAM) is developed and applied in a multiplier analysis setting. The ESAM reproduces the structure of the economy in its entirety, including productive sectors, households and the government, among others, quantifying the nature of all existing economic transactions among diverse economic agents. An ESAM also includes energy flows and emissions in addition to the standard monetary flows. The explicit inclusion of emissions makes it possible to evaluate the emission reduction associated with a specific policy, such as a carbon tax.

The ESAM examines how inputs and outputs flow between sectors of the economy and finally result in final goods consumed by households. The explicit modelling of sectoral inter-linkages makes it possible to investigate the wider economic impacts of a specific shock or policy through the different transmission channels in the economy and the distributional impacts of policies whose effects may be transmitted through multiple markets. The nature of the methodology makes it very useful to examine the direct and indirect impacts of a carbon tax on the Irish economy. This methodology, however, focuses on initial short-term impacts, as it does not consider dynamic decision-making. Future work by the ESRI on the I3E model will include dynamics in a Computable General Equilibrium (CGE) setting.

This report is structured as follows. In the next chapter, we present the methodology that describes the ESAM, the multiplier and the post-multiplier analyses. Chapter 3 describes the results of our analysis, and Chapter 4 draws conclusions.

# CHAPTER 2

## Literature review

Few studies have examined both the economic and environmental impacts of a carbon tax in Ireland. In this review we focus on existing work that includes general equilibrium impacts in the Irish context. The literature to date has examined the potential introduction of a carbon tax in Ireland (pre-2009). Our work is the first to examine an increase in the existing carbon tax.

Wissema and Dellink (2007) develops a Computable General Equilibrium (CGE) model to investigate the impacts of a carbon energy tax in Ireland. They find that a €15 per tonne tax would result in a 25.8% decrease in emissions compared to 1998. Their model includes 23 production sectors and a single household. They are able to include general equilibrium impacts, i.e. investigate the secondary impacts of a carbon tax. Though this work could help gain insight into the impacts of a carbon tax when it was published, it is of little help when investigating the current situation in Ireland. Firstly, it was conducted before the implementation of a carbon tax in Ireland and assumptions were made concerning how this tax would be implemented. A main concern here is the exemptions to the carbon tax such as the electricity sector and Emissions Trading System (ETS) sectors. In Wissema and Dellink's framework there is no distinction between ETS and non-ETS emissions and it assumed that the tax is implemented on all sectors. Secondly, their results are outdated, given that they used Supply and Use data from 1998. The Irish economy has changed significantly in recent decades, and any policy advice would need to take this into account.

Bergin et al. (2004), using the model described in FitzGerald et al. (2002), finds that a carbon tax of €20 would increase energy prices for industry by 26.2% and for households by 14.3%. The tax would modestly reduce $CO_2$ emissions, mostly from power generation. The overall macroeconomic impacts found depend on how the revenue is recycled. If the revenue was used to reduce VAT or social insurance, economic growth would be accelerated, while lump-sum transfers to households or companies would slow growth.

Conefrey et al. (2013) examines the implementation of a €20 carbon tax, focusing on revenue recycling and double dividend. They apply the HERMES model, which is a macroeconomic model including several production sectors. In the HERMES model energy is represented in the production function in a simplistic way. It is a supply-side model and lacks a detailed presentation of the consumption side of the economy. Conefrey et al. (2013) finds that the tax results in an increase of the price of energy inputs to manufacturing of 17% and an increase of energy prices for households of 3.3%. Consumer prices are found to rise by 0.25% and real disposable income decreases by 0.35%. The also find a small decrease in Irish services exports of 0.26%. Overall they find that the volume of GDP at market prices will decrease by 0.21% and total employment by 0.07%. They find evidence of a double dividend when tax is recycled through a reduction in income taxes.

Several studies examine the distributional impacts of a carbon tax in Ireland. By using a similar methodology to this report, Verde and Tol (2009) analyses the effects of a carbon tax on the Irish economy. The authors utilise an input–output (IO) table to obtain the price impacts of introducing a carbon tax and a microsimulation model to quantify the distributive effects. They examine households divided in income deciles and find, as our results also indicate, that a carbon tax is regressive. Our results differ in magnitude, however. Verde and Tol (2009) finds higher impacts for poorer households at approximately €3 per week additional costs and lower impacts for richer households at €4 per week. The results of our study differ for several reasons.

First, we are examining an additional increase to the €20 carbon tax whereas Verde and Tol (2009) investigates the initial implementation of the €20 carbon tax. Second, we replicate the way in which the carbon tax has been implemented in Ireland, whereas Verde and Tol (2009) makes tentative assumptions concerning how it is implemented. Third, the ESAM we have constructed provides more comprehensive data than an IO table to reflect the structure of the economy. Fourth, we have used only one methodology, which makes the results more consistent. When multiple models are used, results are fed from one methodology to another, and the different methodologies rely on diverse frameworks and assumptions.[1] Fifth, the results of Verde and Tol (2009) includes the revenue-recycling effects. Lastly, we have used the most recently available data to construct the ESAM, whereas Verde and Tol utilised the IO table for the year of 2005 and the Household Budget Survey's wave of 2005.

The same arguments concerning the methodology and dataset apply to a more recent study by Lyons et al. (2012), which shows that the distribution of emissions across households is quite sensitive to the household disaggregation. Although the authors do not conduct an economic impact analysis, their results show that the policy implications of an increase in carbon tax would also be sensitive to the household disaggregation choice.

1 The authors use the price information obtained from the IO analysis in the microsimulation model.

Other studies also highlight the limitations of a traditional income decile approach to investigate distributional aspects, although they are not related to the Irish case. An IO-based price analysis by Hassett et al. (2009) shows that the carbon tax has quite regressive effects across households, but the degree of regressivity lessens if households are classified concerning their lifetime incomes based on educational attainment rather than their current level of income. CGE and microsimulation analysis by Rausch et al. (2011) and simulation analysis by Cronin et al. (2017) claims that the within-household groups' variations have more impacts on regressivity of the tax burden than the between-group variations.

The findings of the CGE analysis of Williams et al. (2015) shows that the distributional effects of the carbon tax are more related to the nature of revenue recycling than to the direct price effects of the tax. More specifically, reducing labour income tax has progressive effects while reducing the corporate tax rate amplifies the regressivity of the tax burden. Moreover, a lump-sum rebate to reduce the cost of carbon tax generates the highest regressive effects across households. An overlapping general equilibrium analysis by Diamond and Zodrow (2018) shows that using carbon tax revenues in debt reduction followed by lump-sum per household rebates increases GDP and investment at the expense of lower consumption and labour supply, but the distributional effects become progressive.

Our study is the first attempt to utilise a detailed energy-extended social accounting matrix (SAM) to capture secondary impacts of the carbon tax. Furthermore, it is the first to include both secondary impacts and multiple households within the same framework for Ireland. Most importantly, it uses the latest available data, which cover the effects of the global financial crisis of 2008–9, and is the first study to examine the impacts of increasing the existing carbon tax including the current exemptions in the Irish context.

# CHAPTER 3

# Methodology

This analysis is based on an Energy Social Accounting Matrix (ESAM) that examines how intermediate inputs flow between production sectors of the economy and result in final goods consumed by households. An ESAM makes it possible to track energy inputs through the various production processes and hence to estimate the carbon emissions inherent in the different commodities. Using a multiplier analysis, the implications of an increased carbon tax can then be tracked through the various production processes and commodities in the economy and the final impacts in terms of increased production costs and increased consumption costs for households can be estimated. In this chapter, the concept of an ESAM is introduced, after which the Irish ESAM is discussed. Finally, the multiplier analysis and post-multiplier emission reduction analysis methodologies are discussed.

## 3.1 THE ENERGY SOCIAL ACCOUNTING MATRIX

A SAM can be defined as an organised matrix representation of all transactions and transfers between different production activities (sectors), factors of production (labour, capital and land) and institutions (households, corporate sector, government and enterprises) within an economy and with respect to the rest of the world. A SAM is thus a comprehensive accounting framework within which the full circular flow of an economy (income from production to factors of production which are owned by households who devote their income to consumption, and back to production) is captured.

A SAM depicts all the transactions in the economy in the form of a symmetric matrix. Each economic agent is represented as both a row and a column account. The number of agents represented depends on the nature of the analysis. If a researcher wishes to explore the distributive effects of a policy change, there will be more than one households group. Each row of the SAM gives receipts of an account while the column gives the expenditure. The total of each row has to be equal to the total of the corresponding column. The logic behind this rule is simple; an expenditure of one agent is income of another agent, and an agent's income should equal its expenditure.

Generally, input–output (IO) tables are used to construct SAMs, IO tables are constructed based on supply and use tables (SUTs), which provide the most detailed data on the sources of supply and demand of commodities, the cost of production and taxes and subsidies on products. Industries are on the rows of SUTs while products are on the columns. The supply table provides information on which sectors produce which commodities, imports by commodities, trade margins,[2] taxes and subsidies on products. The use table is formed by using four different tables for domestic use (usage of domestically produced products), import use (usage of imported products), net tax (tax less subsidies) on products, and trade margins. Trade and transportation services are necessary to deliver commodities from factories and docks to markets. Producer prices[3] do not include the cost of the trade and transportation margins, since these are not part of the production process. These costs are paid by final users of commodities and are included in purchaser prices.

Since a commodity is produced by several activities and the cost of margins is paid by consumers, margins are demanded by commodities. Each national statistical office produces an IO table by using SUTs based on either a product technology or an industry technology assumption[4] and regardless of the choice of conversion, each industry is associated with one product in its production process. In other words, IO tables restrict the information provided by SUTs, do not allow industries to produce multi-products and do not allow commodities to be produced by multiple activities. However, secondary and tertiary products may play an important role for some industries and should, therefore, be included. The latter restriction leads to an ignorance concerning differentiated products produced by domestic industries.

In order to avoid the restrictions introduced by IO tables, a SAM can be constructed by directly using the SUTs. In this case, the domestic production can be represented more accurately while several complexities emerge such that each industry has to determine the level of production of each product.

As a SAM records incomes and expenditures, which are flow variables, it provides a snapshot of the economy for a period. Choosing a year for which a SAM is constructed (the base-year), in other words, has important implications. By definition, a SAM depicts the economy in an *accounting equilibrium* where total expenditure is equal to total incomes for each agent. However, *economic equilibrium* requires that each agent does not tend to and has no incentive to change her/his behaviour. In other words, the decisions of agents are stable, which, in turn, requires stability of prices including commodity prices and factors of production prices since the latter determines income

---

2 Usually, the supply table incorporates trade and transportation margins but in the case of Ireland, the Central Statistics Office (CSO) of Ireland provides only trade margin figures.

3 These margins are one of the basic components of the valuation process. For further details, interested readers are advised to see UN (1999) and EUROSTAT (2008, 2013).

4 Details of these assumptions are beyond the focus of this report. They can be found in UN (1999) and Eurostat (2008, 2013).

(cost of production) of households (firms) and the former determines consumption profiles of agents. Therefore, theoretical limitation in choosing a base-year requires choosing a year in which prices are *relatively* stable.

An ESAM includes a further disaggregation of commodities and activities to include energy inputs and emissions. This disaggregation is based on energy-related data. There is no general practice when it comes to including the energy components in a SAM, as no consistent energy data source such as the SUTs is available across countries when constructing the SAM. The inclusion of energy is based on the data available for that country and will differ concerning the method used as well as the level of detail. In the next section, we briefly discuss the method we have used to incorporate energy elements into the ESAM for this report.

## 3.2 STRUCTURE OF THE IRISH ESAM

Based on the discussion of the base-year choice and availability of data, 2011 and 2014 are candidates to be the base-year for the case of Ireland. The latest IO table and SUTs are available for the year of 2011, while only the SUTs are available for the year of 2014. Since we do not need an IO table and want to use the latest available data, 2014 is chosen as the base-year. The information for 2014 is more accurate than that of 2011 since it reflects changes in production and consumption patterns in the Irish economy after the global financial crisis of 2008–9.

A SAM can be constructed for a country, a region or a territory and the choice depends on the focus of analysis. The SAM used in this study represents the entire Irish economy due to the fact that required data, especially on inter-sectoral flows, inter-regional flows of commodities, etc., are not available at a regional level. The aggregated SAM for Ireland is presented in Appendix A.

### 3.2.1 Activities and commodities

The SUTs for 2014 provide information on 58 industries and 58 products. These industries/products are aggregated into 29 industries/products by taking account of relative weights of sectors in total value added and employment and also by considering the importance of sectors in energy–environment-related analyses. These aggregated sectors with their abbreviations and NACE codes are shown in Table B.1 (Appendix B).

### 3.2.2 Energy disaggregation

In order to conduct more accurate analyses of the effects of environmental policies on the Irish economy, some of the energy-related sectors (activities and commodities) in the CSO SUTs given in Table B.1 need to be further disaggregated to the desired level of detail. These sectors have to be disaggregated in such a way that different energy- and environment-related sectors/commodities are represented in both production activities and consumption baskets of final consumers. This process involves distributing the total value of the original sector over the newly created sectors for the activity and commodity rows and columns in the SAM. The disaggregation process requires obtaining information on not only production activities including intermediate input demand composition, the composition of value added by factors of production, etc., but also the distribution of final consumption across private (household) consumption, public consumption, consumption by investment purposes (investment by origin), and exports. The sectors that need to be further disaggregated are Mining, Quarrying and Extraction (MQE), Petroleum, Furniture and Other Manufacturing (PET) and Electricity and Gas Supply (EGS). For this disaggregation, we rely heavily on the SEAI Energy Balance of 2014.[5]

In the case of Mining, Quarrying and Extraction (MQE) a distinction needs to be made between energy and non-energy mining. Energy mining needs to be further disaggregated into peat, coal (which is imported) and natural gas. Other mining includes metal ore, stone, sand, and clay. Based on the Exiobase IO model (de Koning et al., 2011), the CSO SUTs for 2007 (where energy and non-energy mining are separated), SEAI price data, CSO trade data and the Eurostat material flow data,[6] we disaggregate the different mining and quarrying commodities and activities.

In the CSO SUTs, PET has been aggregated to avoid data confidentiality issues, and firstly petroleum will need to be disentangled from furniture and other manufacturing. This is done using the Eurostat SUTs for the EA19 and CSO data concerning the total production and value added of the 'Petroleum' sector and the 'Furniture and Other Manufacturing' sector. The Petroleum commodities then need to be further disaggregated, in order to reflect the compositions of private consumption and intermediate input, into gasoline, kerosene, fuel oil, liquid petroleum gas (LPG), diesel and other petroleum products (petroleum coke, refinery gas, naphtha, bitumen, white spirit and lubricants). This is done on the basis of the SEAI Ireland Energy Balance 2014, which presents national

5 The Energy Balances are available here: https://www.seai.ie/resources/publications/Expanded%20Balances%201990-2015

6 For further details, see http://ec.europa.eu/eurostat/web/environment/material-flows-and-resource-productivity

energy statistics on energy production and consumption in Ireland. The flow of energy from production, transformation, and energy sector own use through to final consumption in different sectors of the economy is given in energy units (kilotonnes of oil equivalent, ktoe). This is then converted into monetary units using different fuel prices derived from, among others, SEAI price data, CSO trade statistics and global fuel prices.

The EGS sector needs to be disaggregated into an electricity sector and a gas sector. This is again done using the SEAI Energy Balance data and price data and CSO trade statistics. Once the different sources of carbon have been separated in the ESAM (coal, crude oil, peat, natural gas, gasoline, kerosene, fuel oil, LPG, diesel and other petroleum products), the corresponding carbon emissions can be calculated. This is done by using fuel-specific conversion factors provided by the SEAI, which give the tonnes of carbon for a ktoe of energy derived from each specific fuel. Carbon tax data are collected from the Revenue Commissioners' excise receipts data and applied to each carbon commodity.

The aforementioned production sectors are thus disaggregated into several sectors including peat, natural gas extraction, other mining, petroleum, furniture and other manufacturing, electricity, and natural gas supply, i.e. 33 sectors in total. Moreover, additional commodities are included, namely gasoline, kerosene, fuel oil, LPG, diesel and other petroleum products. In addition to these domestically produced commodities, the disaggregated SAM also comprises crude oil and coal, which are not produced within Ireland while both of them are demanded as intermediate inputs by refineries and other energy-related sectors and the latter is also demanded for final consumption purposes. Finally, there are 39 commodities in total.

It is important to note that in this analysis, we have focused on carbon commodities and $CO_2$ emissions and do not include other sources of GHG emissions. In Ireland, approximately 30 per cent of GHG emissions originate in the agricultural sector, where the bulk of emissions are non-$CO_2$. The bulk of GHG emissions in agriculture are in the form of methane ($CH_4$) from ruminants and manure, which has a high capacity to trap heat in the atmosphere. Besides methane, nitrous oxide ($N_2O$) is emitted through fertiliser use and animal deposition. A carbon tax does not impact these emissions and further policies will need to be considered in order to limit agricultural emissions. Agricultural emissions discussed in this report refer to $CO_2$ emissions arising from the use of the abovementioned carbon commodities in agricultural production.

### 3.2.3 Households' disaggregation

The household sector is disaggregated into ten income deciles where the first household group, $HH1$, refers to the poorest decile while the tenth group, $HH10$, refers to the richest decile. In the disaggregation process, the available descriptive statistics provided by the CSO for the year 2015 are utilised. These statistics comprise weekly average disposable income of each decile and its distribution across several sources. Summation of employees' wages/salaries and self-employed income is treated as wage income, whereas summation of investment income, property income, own garden/farm produce, and other direct income is treated as capital income, which is used as a proxy of income from enterprises. Summation of the remaining items, including retirement pensions; child benefit; older people pensions; widows, widowers & guardian payments; etc. is treated as transfer income. Then, each household group's shares in these aggregated income items are calculated and total figures for households are distributed across households accordingly.

## 3.3 METHODOLOGY OF PRICE MULTIPLIERS

In Appendix C, a more detailed technical description of the price multiplier methodology is given; here a non-technical description is provided. The work of Pyatt and Round (1979) introduces SAM-based accounting multiplier analysis into the literature. In this methodology, the SAM accounts are divided into exogenous accounts, which are taken as given and determined outside the modelling framework, and endogenous accounts, which are estimated within the modelling framework. A change (shock) can then be implemented in the exogenous account, and its impact on the endogenous accounts can be examined by assuming fixed prices. These multipliers are called accounting or fixed-price multipliers.

An increase in carbon tax, however, directly affects prices of commodities that are taxed due to their carbon content and the interdependencies across the commodities change prices of all other commodities. In this respect, prices should not be fixed in an impact analysis of carbon tax. Therefore, the SAM- based price multiplier analysis, introduced by the seminal paper of Roland-Holst and Sancho (1995), is utilised in this study.[7] The accounts of the government, savings–investments and rest of the world are assumed to be exogenous by referring to Round (2003, p. 6): 'government outlays are essentially policy determined, the external sector is outside domestic control and as the model has

7 For literature on the price multiplier analysis that uses an IO table and focuses on macroeconomic and sectoral effects, see Choi et al. (2010), Perese (2010) and Grover et al. (2016).

no dynamic features, so investment is exogenously-determined'. The methodology is applied to several countries to quantify the price effects of several policy options and changes in external conditions. For instance, Parra and Wodon (2008) provides an impact analysis of changes in oil and food prices on household welfare in Ghana, and Tlhalefang and Galebotswe (2013) conducts the same analyses for the economy of Botswana. The effects of trade liberalisation in several commodities on the Botswanan economy is analysed by Sigwele (2007). Feuerbacher (2014) analyses the effects of income redistribution from urban to rural households and exogenous change on the demand of hydropower by using accounting multipliers and the price effects of a change in cereal prices in Bhutan.

A more recent example of SAM-based price multiplier analysis, Chapa and Ortega (2017), shows the effects of a carbon tax on the Mexican economy. The direct price effects are the highest for fossil fuels and mining sectors, whereas transportation and electricity are the most indirectly affected sectors. Households are disaggregated into eight groups according to poverty situation and geographical region of residence, and the results of distributional analysis reveal that the cost of living of rural-resident households increases more than that of the urban residents, among which the poorest households are the most affected ones, i.e. the effect is regressive.

In our analysis we impose an increase to the existing carbon tax of €5, €10, €15 and €20. We apply the increase in the same way as the existing tax, i.e. the current ETS, agricultural and other exemptions hold. Furthermore, a minimum carbon charge is imposed in Ireland on the use of coal at €4 per tonne of carbon, which also applies to ETS sectors; we assume that this minimum charge is increased in line with the carbon tax increase.

## 3.4 POST-MULTIPLIER ANALYSIS

As mentioned above, the employed price multiplier methodology explores the effects of a change on the exogenous accounts via prices by keeping all quantities including intermediate inputs fixed. Therefore, it does not allow us to draw conclusions concerning changes in emissions. In order to quantify the potential effects of changes in prices due to increases in the carbon tax, the following post-multiplier analysis is designed.

As the saving-investment account is assumed to be fixed, sectoral capital stocks are also fixed. In addition to fixed employment, this implies that total value added remains fixed. The assumption of this methodology concerning fixed quantities holds for the total volume of outputs as well. As a result, the question of post-multiplier analysis is 'What would be the changes in intermediate input compositions of activities due to increases in the carbon tax for the fixed levels of value added and output?' Similarly, households alter their composition of consumption expenditures due to changes in prices for the fixed levels of disposable income.

It must be noted that these results are obtained under restrictive assumptions and therefore should be interpreted with caution. The results can be interpreted as the direct effects of price changes. On the other hand, changes in energy-related input prices would also affect real value added and thus factor prices and market income of households. Moreover, changes in prices would also affect government revenues and thus transfers to households and disposable incomes of households. In other words, the methodology employed does not allow us to quantify these general equilibrium effects.[8]

Figures in Appendix E show the nested structures of private composite consumption and production in detail. The primary objective of creating such detailed nested structures is to reflect the compositions of households' and activity's demands on energy commodities more accurately. In this sense, the way the nested structure is defined determines the substitutability between inputs to production and between goods for consumption. If goods are nested together, this represents a higher substitutability between these goods compared to others. A Leontief relationship assumes a low level of substitutability as compared to a constant elasticity of substitution (CES) relationship. The values of elasticity of substitution parameter, sigma, for different elasticity relations are chosen in order to reflect the low and high substitution possibilities among the commodities based on expert judgement.

Household composite consumption, *CC*, is assumed to be a constant elasticity of substitution (CES) aggregate of composite commodities of Transportation (*T RP*), Residential Energy (*REN*), Nourishment (*NTR*), Services (*SER*), and other commodities (*OTC*), shown in Figure E.1. As described above, this reflects the fact that different goods relating to e.g. services are easier to substitute with each other than, for example, substituting services with nourishment. The logic here is that consumers are more likely, for example, to substitute food products with agricultural products if prices of food products increase than to increase their consumption of services as food prices increase. The commodity *TRP* is a Leontief aggregate of land, air, and water transportation commodities where the land transportation (*LND*) is also a Leontief aggregate of public and private transportation commodities. The choice of a Leontief

8 The CGE model under construction, namely the Ireland Environment Energy Economy (I3E) model, will be able to serve this purpose and examine the effects of a price change over several dimensions.

relationship here reflects the low level of substitutability between transport types. A consumer will not substitute their daily car commute with air or water transport as petrol prices increase. It should be noted that the original land transportation commodity (*LTS* with NACE Code 49) covers the public transportation demand of households. Since households demand some of the energy commodities including gasoline, diesel, liquid petroleum gas and electricity for private transportation purposes, the composite commodity *LND* is assumed to be a CES aggregate of those energy commodities. The *REN* is disaggregated into lighting electricity and residential heating, which is further disaggregated into natural gas supply, solid fuel, heating electricity and liquid fuel. Moreover, solid (liquid) fuel is a CES (Leontief) aggregate of peat and coal (kerosene and fuel-oil). The total electricity consumption of households, the commodity *ELC*, is known from the SAM, and it is disaggregated into electricity demand by transportation, lighting, and heating purposes by using the data provided by SEAI (2013, Table 19). The composite commodity *NTR* is a CES aggregate of the commodities agriculture and food, beverage and tobacco while the composite commodity *SER* is a CES aggregate of several service commodities. The composite commodity *OTC* is a CES aggregate of all remaining commodities that are demanded by households.

On the production side, the activities are assumed to produce a composite product *QX* which is a CES aggregate of value added (*VA*), business energy (*BEN*) and other inputs (*OTI*). The value added is a CES aggregate of factors of production, capital and labour, and the commodity *OTI* is a CES aggregate of all except the energy commodities. For all activities, except the electricity production, the commodity *BEN* is assumed to be a Leontief aggregate of energy electricity, fuel (*FUE*) and business heating (*BH*). The composite commodity *BH* is a CES aggregate of liquid and solid fuels including coal, peat, crude oil, natural gas supply, and business electricity for heating purposes, i.e. the first subset of energy commodities. The structure of the composite commodity *FUE* is differentiated across activities by considering the different compositions of their demands. To this end, the activities are assigned in five groups.[9] The commodity *FUE* constitutes the energy commodities of natural gas extraction, gasoline, kerosene, fuel oil, liquid petroleum gas and diesel, i.e. the second subset of energy commodities, but the combination of these commodities to generate the *FUE* differs. For the first group of activities, *FUE* is a Leontief aggregate of natural gas extraction and other fuels (*OTF*1), which is a CES aggregate of the remaining energy commodities. For the second (third) group, the *FUE* is a Leontief aggregate of diesel (fuel oil) and other fuels *OTF*2 (*OTF*3), which is a CES aggregate of the other energy commodities. For the fourth (fifth) group, the composite commodity *FUE* is a CES (Leontief) aggregate of all commodities in the

9 The list of activities by group can be found in Appendix B.

second subset of energy commodities. The electricity production activity solely represents the sixth group concerning its production technology and energy demand composition. The activity's business energy, *BEN*, is assumed to be a Leontief aggregate of electricity, natural gas supply, and other energy (*OTE*), which is a CES aggregate of all remaining energy commodities. The electricity demand of activities, except the electricity production, is disaggregated across demands for energy purposes and heating/combustion purposes.[10]

The post-multiplier analysis allows households and activities to alter their consumption and intermediate input demands, respectively, due to changes in purchaser prices of the commodities. As the commodity demands change, the household and activity-based emissions also change. In the calculation of these emissions, the quantity of demand (consumption or intermediate input) is multiplied by the per unit emission intensity of commodity *c*. This parameter is calibrated by dividing the available emissions by commodities by the initial levels of total consumptions of the energy commodities.

10 At this stage, the disaggregation is done by arbitrarily assuming that 40 per cent (60 per cent) of the total sectoral electricity is used for heating/combustion (energy) purpose.

# CHAPTER 4

# Results

The focus of this report is on evaluating the effects of a €5 increase in carbon tax per tonne of $CO_2$ on commodities in the non-ETS sector. We also extend our analysis to investigate further increases in the carbon tax of €10, €15 and €20. We first give a brief overview of the current carbon tax in place, after which we examine by how much the sales tax on each carbon commodity will increase if the carbon tax is increased. Using our price multiplier analysis, we then examine the distributional implications of an increased carbon tax for production sectors, where we focus on which production sectors face the highest production cost increases. The implications for household consumption prices are then investigated, with a focus on the increase in energy costs and the possible implications for fuel poverty. Finally, applying our post-multiplier analysis, we investigate the potential emission reduction associated with an increase in carbon taxes.

The impacts presented in this chapter should be seen as short-term impacts, where both producers and consumers do not fully internalise the effects of policy changes given the static setting.

## 4.1 CURRENT IRISH CARBON TAX POLICY

In 2009, a carbon tax was introduced in Ireland covering transport fuels (petrol and diesel). The tax was levied based on the carbon content of the fuels, applying a rate of €15 per tonne of $CO_2$. It was extended in 2010 to include non-transport fuels (kerosene, marked gas oil, LPG and natural gas) and in 2013 to include solid fuels (coal and peat). Currently, the tax is levied on the supply of solid fuels, natural gas and mineral oils based on their carbon content, where a rate of €20 per tonne of $CO_2$ is applied. The tax applies tonon-ETS sectors and excludes carbon used in electricity generation or as inputs to the production of carbon products, though there is a minimum rate for all coal.

Table 4.1 shows the carbon taxes levied on the various forms of carbon in € millions. Our analysis is based on 2014, the latest year for which Supply and Use data are available, where total carbon tax levied was €390 million. The latest carbon tax data are available for 2016 and are of a similar magnitude in total and across different carbon sources. Transport fuels (diesel and petrol) constitute a large share of the total carbon tax levied, though the carbon tax accounts for 7.6% of total excise duties levied on petrol and 14% of total excise duties on diesel. The overall carbon tax is relatively low, where total carbon tax constituted a mere 1.9% of total taxes levied on commodities in Ireland in 2014.

TABLE 4.1 IRISH CARBON TAX LEVIED FOR VARIOUS FUELS IN 2014

| Fuel type | €m |
|---|---|
| Diesel | 147.6 |
| Petrol | 67.5 |
| Marked gas oil | 54.2 |
| Natural gas extraction | 51.7 |
| Kerosene | 42.3 |
| Solid fuels (coal and peat) | 17.2 |
| LPG | 7.6 |
| Fuel oil | 1.8 |

## 4.2 CARBON COMMODITY SALES TAX

An increase in the carbon tax of €5 will result in increased sales tax rates on carbon inputs, which are calculated as the share of sales tax in the total supply value of each commodity. Table 4.2 gives the current sales tax, the computed new sales tax for carbon inputs and the percentage change in sales tax. Since other commodities are not taxed under the carbon tax, there are no changes in their sales tax rates. Although the other commodities do not pay the carbon tax, interdependencies across activities and commodities affect all prices, i.e. as carbon input prices increase due to an increase in carbon taxes, prices of commodities using carbon inputs in their production will also increase.

The impact that an increase in carbon tax will have on total sales tax of a given carbon commodity will depend on two factors. Firstly, the smaller the share of carbon tax receipts in total sales tax receipts, the smaller will be the impact of an increase in the carbon tax. Table 4.2 illustrates this, where a high rate of sales tax is shown for gasoline (petrol) and diesel, 0.683 and 0.470 respectively. As discussed above, these sales taxes consist mostly of non-carbon excise duties. Therefore, a €5 increase in carbon tax has a relatively small impact on the total sales tax rates of these commodities, namely 3.2% for gasoline and 5.1% for diesel. On the contrary, the share of carbon tax receipts in total sales tax receipts is larger for other carbon commodities (e.g. 64% for fuel oil, 97% for LPG, and 100% for kerosene), resulting in more substantial impacts on the total sales tax for these commodities. Secondly, to a lesser extent, the carbon content of the carbon commodity has an impact on the change in total sales tax, where an increase in the carbon tax has more impacts on the sales tax of carbon commodities with higher carbon contents such as coal and peat. This impact is rather small, as the difference in relative prices of carbon commodities negates most of these impacts, i.e. the prices of carbon commodities are closely related to their carbon content.

TABLE 4.2 SALES TAX RATES BY CARBON COMMODITIES

| | Sales tax (%) | New sales tax (%) | Percentage change |
|---|---|---|---|
| Peat | 3.5 | 4.2 | 20.00 |
| Coal | 4.6 | 5.6 | 21.74 |
| Natural gas extraction | 4.0 | 4.8 | 20.00 |
| Gasoline | 68.3 | 70.5 | 3.22 |
| Kerosene | 2.1 | 2.6 | 23.81 |
| Fuel-oil | 0.3 | 0.4 | 33.33 |
| LPG | 4.0 | 5.0 | 25.00 |
| Diesel | 47.0 | 49.4 | 5.11 |

*Note:* *The second column is the original effective sales tax rate on energy commodities. The third column is the new tax rate after an increase in carbon tax by €5. The fourth column shows the percentage change in sales tax rate.*

## 4.3 CARBON COMMODITY PURCHASER PRICES

We now examine how purchaser prices will be impacted by an increase in the carbon tax. Table 4.3 shows the purchaser price increases of carbon commodities in percentages. It is clear from these results that increasing the carbon tax will not have extreme impacts on the prices of carbon commodities; for example, doubling the carbon tax to €40 per tonne will lead to an average 3.4% increase in purchaser prices for carbon commodities. Even when looking at diesel, which is the commodity with the highest change in purchaser prices, increases in purchaser prices are relatively small: a carbon tax of €40 will result in an increase of purchaser price of 7.1%. This is comparable in size to the (exogenous) diesel price fluctuations faced by consumers in the first five months of 2018.

Comparing the impacts across carbon commodities, the results in Table 4.3 indicate that, despite the lowest percentage changes in sales tax rates, the most affected commodities are diesel and gasoline. The reason for this lies in the structure of the multiplier. The value of the multiplier depends on the composition of commodity production by activities and the composition of intermediate input by activities, respectively. The higher share of diesel shows the importance of this commodity in the production process. Furthermore, the level of the carbon tax as a fraction of total supply is the highest for diesel.

## 4.4 PRODUCER PRICES

When interpreting the results here concerning producer and consumer prices, it is essential to keep in mind the assumptions of the methodology applied. This methodology considers the initial impacts of a carbon tax, where producers and households do not adjust their behaviour in response to price changes. The advantage of this methodology is that it focuses on the initial impacts, which are generally the largest. As producers and consumers adjust their behaviours, these impacts can be negated to a degree.

TABLE 4.3 CHANGES IN PURCHASER PRICES OF CARBON COMMODITIES (PER CENT)

| | €5 | €10 | €15 | €20 |
|---|---|---|---|---|
| Peat | 0.699 | 1.407 | 2.127 | 2.858 |
| Coal | 0.946 | 1.909 | 2.891 | 3.892 |
| Natural gas extraction | 0.779 | 1.570 | 2.373 | 3.189 |
| Gasoline | 1.323 | 2.682 | 4.078 | 5.512 |
| Kerosene | 0.528 | 1.063 | 1.603 | 2.148 |
| Fuel-oil | 0.081 | 0.163 | 0.245 | 0.328 |
| LPG | 0.996 | 2.012 | 3.049 | 4.107 |
| Diesel | 1.687 | 3.432 | 5.238 | 7.108 |
| Natural gas supply | 0.324 | 0.653 | 0.988 | 1.328 |

*Note:* *Changes in purchaser prices of energy commodities due to an increase in carbon tax of €5, €10, €15 and €20.*

Simply put, we assume that consumers do not change their consumption behaviour and feel the full force of the carbon tax; however, in reality, consumers will adjust their consumption bundles and consume less carbon-intensive goods. The degree to which both producers and consumers will adjust their behaviours will depend on various factors.

TABLE 4.4 CHANGES IN PRODUCER PRICES OF SELECTED ACTIVITIES (PER CENT)

| | €5 | €10 | €15 | €20 |
|---|---|---|---|---|
| Natural gas supply | 0.345 | 0.696 | 1.052 | 1.414 |
| Water transportation services | 0.282 | 0.573 | 0.875 | 1.186 |
| Air transportation services | 0.263 | 0.533 | 0.809 | 1.092 |
| Land transportation services | 0.261 | 0.531 | 0.809 | 1.098 |
| Electricity | 0.138 | 0.280 | 0.424 | 0.571 |
| Natural gas extraction | 0.130 | 0.263 | 0.398 | 0.536 |
| Agriculture | 0.088 | 0.179 | 0.273 | 0.371 |
| Accommodation and related services | 0.078 | 0.158 | 0.241 | 0.326 |
| Construction | 0.063 | 0.129 | 0.196 | 0.265 |
| Transportation equipment | 0.051 | 0.103 | 0.157 | 0.213 |
| Peat | 0.048 | 0.097 | 0.148 | 0.200 |
| Food, beverage and tobacco | 0.044 | 0.088 | 0.134 | 0.182 |
| Textile | 0.040 | 0.081 | 0.123 | 0.167 |
| Petroleum | 0.032 | 0.066 | 0.100 | 0.135 |
| Chemicals and chemical products | 0.030 | 0.060 | 0.091 | 0.123 |
| Basic pharmaceutical products | 0.017 | 0.034 | 0.051 | 0.069 |

*Note: Changes in producer prices of selected activities due to an increase in carbon tax of €5, €10, €15 and €20.*

Examining the impacts of total producer prices across production sectors, we can gain a better understanding of the production sectors most affected by a carbon tax increase. Table 4.4 gives the percentage change in producer prices for the 16 most impacted production sectors (the impacts on all production sectors are displayed in Appendix D. The results in Table 4.3 drive the changes in producer prices here, where the natural gas supply sector is the most affected since energy commodities constitute the majority of intermediate inputs of the sector. As the purchaser prices of the energy commodities increase, the cost of production and thus the producer price of the natural gas supply sector increases. The impact, however, remains small, with a less than 0.35% increase in producer prices in the case of a €5 increase in the carbon tax. When an increase of €20 is applied, the effects become higher than 1.4%. This sector is followed by the transportation sectors (water, land and air) due to the relatively high increases in the purchaser prices of diesel and gasoline, though the impacts remain low at less than 0.3% with a €5 increase in the carbon tax. Among these services, water transportation is affected the most since diesel is the primary source of energy for the sector. Electricity and agriculture follow the transportation services. For the remaining activities, the effects are negligible.[11]

TABLE 4.5 EXPORT SHARES OF COMMODITIES (PER CENT)

| | |
|---|---|
| Water transportation services | 0.097 |
| Air transportation services | 1.840 |
| Land transportation services | 0.068 |
| Electricity | 0.009 |
| Agriculture | 0.695 |
| Accommodation and related services | 0.316 |
| Transportation equipment | 0.151 |
| Food, beverage and tobacco | 9.005 |
| Textile | 0.177 |
| Chemicals and chemical products | 6.782 |
| Basic pharmaceutical products | 16.412 |

*Note:* *Export shares of commodities in total exports. As all activities produce multiple commodities, we cannot trace which activities export which commodities. However, given that the bulk of commodities are produced by the corresponding sector, we trace export of commodities.*

Obviously, increasing domestic prices have repercussions on the international competitiveness of the Irish economy, as export prices rise with domestic prices. Table 4.5 shows each commodity's share in total exports for the most impacted sectors (in terms of producer price increases), as was shown in Table 4.4. These figures indicate that the commodities with the highest price increases due to an increased carbon tax have low shares in the total Irish exports. The sectors with a significant share of exports, namely food, beverage and tobacco, chemicals and chemicals products, and basic pharmaceutical products, will face relatively small increases in producer prices (0.031% and below). This would indicate that an increased carbon tax will have no significant

11 Note that the impacts of a carbon tax on electricity are overestimated here, as a carbon tax on peat does not apply to the electricity sector but in this analysis cannot be disentangled from the carbon tax applied to peat for other uses. We also assume that the minimum charge for coal used in electricity generation increases by the same percentage as the carbon tax. These effects do not impact the other results significantly but should be mentioned here.

impacts on Irish exports.[12]

## 4.5 CONSUMER PRICES

An important issue concerning the implementation of a fair carbon tax is its distributional impact across households. Here we examine how consumer prices of different household types are affected, where household types are distinguished based on their income, i.e. we examine income deciles. Table 6 presents these results, where the bottom row shows the effects of a carbon tax shock on the overall inflation measured by changes in the consumer price index. The inflationary impacts are quite low, as carbon commodities constitute a relatively small share of total private consumption, namely 2.7% in diesel, 2.2% in gasoline and 2% in electricity. In terms of the price impacts across household types, the effects are lowest for the richest and the poorest deciles, which are followed by the two next poorest deciles, and highest for the sixth decile.

TABLE 4.6 CHANGES IN CONSUMER PRICE INDEX (PER CENT)

| | €5 | €10 | €15 | €20 |
|---|---|---|---|---|
| The poorest | 0.117 | 0.236 | 0.359 | 0.486 |
| HH2 | 0.124 | 0.251 | 0.381 | 0.516 |
| HH3 | 0.129 | 0.262 | 0.398 | 0.539 |
| HH4 | 0.132 | 0.269 | 0.409 | 0.553 |
| HH5 | 0.129 | 0.262 | 0.398 | 0.539 |
| HH6 | 0.135 | 0.273 | 0.416 | 0.563 |
| HH7 | 0.131 | 0.267 | 0.406 | 0.549 |
| HH8 | 0.129 | 0.261 | 0.398 | 0.539 |
| HH9 | 0.129 | 0.262 | 0.400 | 0.541 |
| The richest | 0.117 | 0.238 | 0.362 | 0.490 |
| Overall | 0.127 | 0.258 | 0.392 | 0.531 |

*Note:* *Changes in household-specific consumer price indices due to an increase in carbon tax of €5, €10, €15 and €20. The bottom row shows the effects on the overall CPI (see Section 3.3 for the definition).*

12 Note that currently the Irish carbon tax does not cover agricultural emissions. A carbon tax on agricultural emissions could have significant ramifications for Irish agricultural exports.

Although there is a negative correlation between the share of electricity in total household consumption and household income, i.e. as income increases the share declines, this is not the case for gasoline and diesel. Table 4.7 indicates that gasoline has a hump-shaped pattern across households while the budgetary share of diesel increases consistently as income increases (with the exception of HH5) and then declines for the richest households. In summary, an increased carbon tax does not make poorer households worse off (in terms of increased prices) as compared to richer, due to the higher share of diesel and gasoline in the richer households' consumption basket.

An important policy issue in Ireland is that of fuel poverty. The impact of the carbon tax, and more importantly future potential increases in the carbon tax, on fuel poverty needs to be considered when implementing a carbon tax. Fuel poverty occurs when people are unable to afford to heat their homes adequately. This leads to people living in cold, damp and thermally inefficient housing, which in turn results in adverse impacts on health. Fuel poverty predominantly affects low-income households, defined as households that spend more than 10% of their disposable income on energy costs.

To investigate the potential impacts of a carbon tax on fuel poverty, we calculate the change in the energy CPI, where only energy-related commodities are included in the consumption bundle, and the heating CPI, which includes only heating costs. Using this method we can gain some insights into the impacts on energy prices for different households. Examining how energy costs for the poorest households are impacted can in turn give some limited insights on how fuel poverty may be impacted; this should, however, not be seen as a comprehensive analysis of fuel poverty.

TABLE 4.7 BUDGET SHARES OF ENERGY COMMODITIES BY HOUSEHOLD (PER CENT)

| | The poorest | HH2 | HH3 | HH4 | HH5 | HH6 | HH7 | HH8 | HH9 | The richest |
|---|---|---|---|---|---|---|---|---|---|---|
| Electricity | 3.63 | 3.02 | 2.69 | 2.57 | 2.34 | 2.14 | 2.01 | 1.71 | 1.55 | 1.33 |
| *Lighting* | 2.32 | 1.94 | 1.72 | 1.65 | 1.50 | 1.37 | 1.28 | 1.09 | 0.99 | 0.85 |
| *Heating* | 1.16 | 0.97 | 0.86 | 0.82 | 0.75 | 0.68 | 0.64 | 0.55 | 0.50 | 0.43 |
| *Transportation* | 0.15 | 0.12 | 0.11 | 0.10 | 0.09 | 0.09 | 0.08 | 0.07 | 0.06 | 0.05 |
| Gasoline | 2.40 | 2.47 | 2.72 | 2.70 | 2.75 | 2.71 | 2.50 | 2.07 | 1.86 | 1.59 |
| Kerosene | 1.53 | 1.32 | 1.13 | 0.95 | 0.93 | 0.87 | 0.78 | 0.69 | 0.59 | 0.48 |
| Diesel | 1.48 | 2.18 | 2.26 | 2.63 | 2.55 | 2.85 | 2.86 | 2.97 | 3.24 | 2.74 |
| Natural gas supply | 0.81 | 0.70 | 0.67 | 0.63 | 0.67 | 0.54 | 0.56 | 0.52 | 0.46 | 0.50 |
| Coal | 0.56 | 0.32 | 0.29 | 0.26 | 0.18 | 0.16 | 0.15 | 0.10 | 0.11 | 0.07 |
| Peat | 0.41 | 0.23 | 0.21 | 0.19 | 0.13 | 0.12 | 0.11 | 0.07 | 0.08 | 0.05 |
| LPG | 0.08 | 0.07 | 0.06 | 0.05 | 0.05 | 0.05 | 0.04 | 0.04 | 0.03 | 0.03 |
| Fuel-oil | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

*Note: Shares of energy commodities in total household consumption. These shares are used to calculate CPI, energy CPI and heating CPI.*

TABLE 4.8 CHANGES IN SPECIFIC CONSUMER PRICE INDICES (PER CENT)

| | Energy CPI | | | | Heating CPI | | | |
|---|---|---|---|---|---|---|---|---|
| | €5 | €10 | €15 | €20 | €5 | €10 | €15 | €20 |
| The poorest | 0.701 | 1.419 | 2.157 | 2.915 | 0.277 | 0.558 | 0.843 | 1.133 |
| HH2 | 0.814 | 1.650 | 2.510 | 3.395 | 0.254 | 0.511 | 0.773 | 1.037 |
| HH3 | 0.866 | 1.757 | 2.674 | 3.617 | 0.253 | 0.509 | 0.769 | 1.032 |
| HH4 | 0.916 | 1.858 | 2.827 | 3.826 | 0.241 | 0.485 | 0.732 | 0.984 |
| HH5 | 0.932 | 1.892 | 2.879 | 3.896 | 0.233 | 0.470 | 0.710 | 0.953 |
| HH6 | 0.985 | 1.999 | 3.043 | 4.118 | 0.232 | 0.467 | 0.705 | 0.947 |
| HH7 | 0.995 | 2.020 | 3.076 | 4.164 | 0.228 | 0.458 | 0.692 | 0.929 |
| HH8 | 1.036 | 2.103 | 3.202 | 4.336 | 0.223 | 0.450 | 0.679 | 0.912 |
| HH9 | 1.082 | 2.198 | 3.348 | 4.534 | 0.228 | 0.459 | 0.694 | 0.931 |
| The richest | 1.068 | 2.169 | 3.304 | 4.475 | 0.216 | 0.435 | 0.658 | 0.883 |

*Note:* *Changes in household-specific specialised consumer price indices due to an increase in carbon tax of €5, €10, €15 and €20. The energy CPI comprises all energy commodities while the heating CPI comprises all but gasoline, diesel, LPG and electricity demand for private transportation purposes.*

The impacts on energy CPI are not lower than 0.7% for a €5 increase in carbon tax since the price effects on these products are naturally relatively high among all commodities. On the other hand, the heating CPI, which comprises all heating-related commodities, i.e. energy commodities except gasoline, diesel, LPG, and electricity for private transportation purposes, indicates that, although it is the highest for the poorest decile, the effects of an increase in carbon tax are quite uniform across household deciles. In other words, the dispersion of changes in the heating CPI is lower than that of the energy CPI. Overall impacts on heating prices are relatively small, whereby heating prices increase by around 0.23% for all households in the case of a €5 increase and less than 1% for a €20 increase. This suggests that an increased carbon price will have a small impact on fuel poverty.

## 4.6 MONETARY COST FOR HOUSEHOLDS

Increasing purchaser prices will impact households' budgets. To gain a better understanding of the cost increases for each household type, we examine the estimated weekly additional costs per household type in euro terms. Assuming that households keep their consumption bundles constant, Table 4.9 shows the weekly average cost of increasing purchaser prices for household deciles due to an increase in a carbon tax of €5, €10, €15 and €20.

TABLE 4.9 WEEKLY MONETARY COST BY HOUSEHOLD

| | €5 | €10 | €15 | €20 |
|---|---|---|---|---|
| The poorest | 0.45 | 0.91 | 1.38 | 1.87 |
| HH2 | 0.62 | 1.26 | 1.92 | 2.60 |
| HH3 | 0.82 | 1.66 | 2.53 | 3.42 |
| HH4 | 1.00 | 2.04 | 3.10 | 4.20 |
| HH5 | 1.10 | 2.23 | 3.39 | 4.59 |
| HH6 | 1.33 | 2.70 | 4.12 | 5.57 |
| HH7 | 1.46 | 2.97 | 4.51 | 6.11 |
| HH8 | 1.73 | 3.52 | 5.36 | 7.25 |
| HH9 | 2.01 | 4.07 | 6.21 | 8.40 |
| The richest | 2.30 | 4.67 | 7.11 | 9.63 |

*Note:* *Weekly average cost (in euro terms) of increasing purchaser prices for household deciles due to an increase in carbon tax of €5, €10, €15 and €20.*

The results indicate that a €20 increase in carbon tax leads to a €9.6 increase in total consumption expenditures of the richest household while the effect decreases as income decreases, whereby the poorest household faces a €1.9 increase. Table 4.10 shows the disaggregation of the monetary cost between energy and non-energy commodities. Accordingly, two-thirds of the monetary cost comes from the energy commodities, and this ratio is almost uniform across households.

TABLE 4.10 WEEKLY MONETARY COST BY COMPONENTS

| | Energy | | | | Non-energy | | | |
|---|---|---|---|---|---|---|---|---|
| | **€5** | **€10** | **€15** | **€20** | **€5** | **€10** | **€15** | **€20** |
| The poorest | 0.30 | 0.61 | 0.93 | 1.26 | 0.15 | 0.30 | 0.45 | 0.61 |
| HH2 | 0.43 | 0.87 | 1.33 | 1.80 | 0.19 | 0.39 | 0.59 | 0.80 |
| HH3 | 0.56 | 1.14 | 1.74 | 2.35 | 0.26 | 0.52 | 0.80 | 1.08 |
| HH4 | 0.70 | 1.43 | 2.17 | 2.94 | 0.30 | 0.61 | 0.93 | 1.26 |
| HH5 | 0.77 | 1.57 | 2.39 | 3.23 | 0.33 | 0.66 | 1.00 | 1.36 |
| HH6 | 0.93 | 1.90 | 2.88 | 3.90 | 0.40 | 0.81 | 1.23 | 1.67 |
| HH7 | 1.01 | 2.05 | 3.13 | 4.23 | 0.45 | 0.91 | 1.39 | 1.88 |
| HH8 | 1.15 | 2.34 | 3.56 | 4.82 | 0.58 | 1.18 | 1.79 | 2.43 |
| HH9 | 1.35 | 2.73 | 4.16 | 5.64 | 0.66 | 1.34 | 2.04 | 2.76 |
| The richest | 1.44 | 2.93 | 4.46 | 6.04 | 0.86 | 1.74 | 2.65 | 3.59 |

*Note:* *Weekly average cost (in euro terms) of increasing purchaser prices for household deciles due to an increase in carbon tax of €5, €10, €15 and €20.*

TABLE 4.11 COST-TO-INCOME RATIO (PER CENT)

| | €5 | €10 | €15 | €20 |
|---|---|---|---|---|
| The poorest | 0.160 | 0.325 | 0.493 | 0.667 |
| HH2 | 0.121 | 0.245 | 0.372 | 0.504 |
| HH3 | 0.120 | 0.244 | 0.372 | 0.503 |
| HH4 | 0.124 | 0.251 | 0.381 | 0.516 |
| HH5 | 0.120 | 0.243 | 0.371 | 0.501 |
| HH6 | 0.131 | 0.266 | 0.404 | 0.547 |
| HH7 | 0.119 | 0.241 | 0.367 | 0.497 |
| HH8 | 0.114 | 0.232 | 0.353 | 0.478 |
| HH9 | 0.110 | 0.223 | 0.340 | 0.461 |
| The richest | 0.068 | 0.138 | 0.210 | 0.284 |

*Note: Cost-to-income ratios for household deciles due to an increase in carbon tax of €5, €10, €15 and €20.*

Another indicator of distributive impacts of an increase in carbon tax is the monetary cost-to-income ratios across households. The results in Table 4.9 indicate that the monetary costs, not surprisingly, are increasing with household income. However, cost-to-income ratios (Table 4.11) clearly show that the effects relative to household disposable incomes are regressive across households, i.e. poorer households will have to spend a higher share of their income compared to richer households to retain their initial consumption.

## 4.7 EMISSION REDUCTIONS

Here, we apply our post-multiplier analysis to gain an understanding of how producers and consumers may react to an increased carbon price and what the resulting impacts on emission reductions will be. Table 4.12 shows the changes in activity-based (production) emissions. Note that these results are based on changes in the compositions of intermediate demands of activities due to changes in relative prices of commodities under the assumption that the quantities of value added and output are fixed. In other words, we assume that an activity produces the same quantity but uses different inputs to lower its production costs. Given this assumption, activities substitute energy inputs for non-energy inputs, which in turn lowers $CO_2$ emissions. Therefore, the results on emissions are overestimated and results should be interpreted with this in mind.

Examining the results, we see that emission reductions are the highest in the transportation activities (water and land), where a €5 increase in the carbon tax will reduce this sector's emissions by 2.5%. The transportation activities are followed by peat and agriculture, with emission reductions of 2.4% and 1.9% respectively. Note here that we only examine carbon-related $CO_2$ emissions of the agricultural sector and do not consider other GHG emissions resulting from agriculture, such as methane and nitrous oxide, i.e. we do not consider the bulk of GHG emissions resulting from the agricultural sector.

TABLE 4.12 CHANGES IN SELECTED ACTIVITY-BASED EMISSIONS (PER CENT)

| | €5 | €10 | €15 | €20 |
|---|---|---|---|---|
| Water transportation services | −2.496 | −4.966 | −7.410 | −9.829 |
| Land transportation services | −2.460 | −4.898 | −7.311 | −9.702 |
| Peat | −2.371 | −4.724 | −7.059 | −9.375 |
| Agriculture | −1.948 | −3.897 | −5.849 | −7.802 |
| Construction | −1.525 | −3.056 | −4.594 | −6.138 |
| Chemicals and chemical products | −1.091 | −2.180 | −3.266 | −4.350 |
| Air transportation services | −1.077 | −2.154 | −3.232 | −4.311 |
| Petroleum | −1.071 | −2.140 | −3.207 | −4.271 |
| Food, beverage and tobacco | −0.977 | −1.953 | −2.928 | −3.902 |
| Natural gas extraction | −0.972 | −1.941 | −2.908 | −3.872 |
| Natural gas supply | −0.835 | −1.668 | −2.496 | −3.322 |
| Electricity | −0.719 | −1.439 | −2.158 | −2.878 |
| Accommodation and related services | −0.708 | −1.426 | −2.155 | −2.893 |
| Textile | −0.460 | −0.923 | −1.388 | −1.856 |
| Basic pharmaceutical products | −0.398 | −0.799 | −1.203 | −1.610 |
| Transportation equipment | −0.323 | −0.648 | −0.975 | −1.304 |

*Note:* *Changes in activities' emissions as a result of altered intermediate input compositions due to an increase in carbon tax of €5, €10, €15 and €20.*

Not surprisingly, the most impacted sectors, as displayed in Table 4.12 consist mainly of transportation activities (water, land, and air) and energy-related activities (peat, petroleum, natural gas extraction, natural gas supply, electricity). The energy and transportation sectors; construction; chemical and chemical products; food, beverage and tobacco; and accommodation have the highest emissions reduction. Other sectors show relatively small emissions reduction, under 0.5% for a €5 increase.

For larger increases in the carbon tax emission reductions increase; for example, for a €20 increase emissions from transportation activities decrease by almost 10%. These are still relatively small numbers given that transport constitutes about a third of Irish emissions and would need significantly larger reductions to meet the emissions targets.

Considering household emissions, Table 4.13 shows that the reduction in emissions and household income have a negative correlation. In other words, richer households will reduce their emissions more than poorer households in reaction to the carbon tax increase. This result is in line with the notion that the reduction of consumption of energy goods is less likely for poorer households as they consume more essential energy goods, while richer households consume more non-essential energy goods where possibilities of substitution with other goods are higher.

The impacts of an increase in carbon tax by €5 on economy-wide emissions are given in the bottom row of Table 4.13, where the total emissions are reduced by slightly less than 1.2%. Given the aforementioned caveats of our methodology, we believe our results are likely to overestimate the emission reduction associated with an increase in the carbon tax. In other words, a €5 increase in carbon tax will in a best-case scenario lead to a 1.2% reduction of total non-ETS $CO_2$ emissions. On doubling carbon tax to a rate of €40 per tonne of $CO_2$, total emission reduction is estimated at 4.8%. The non-ETS reduction target for Ireland stands at 20 per cent compared to 2005 levels by 2020. $CO_2$ emissions in Ireland have fallen compared to 2005: the EPA (2018) estimates that non-ETS emissions have reduced from 47,146 kilotonnes in 2005 to 41,363 in 2014 and 43,810 in 2016. However, the reason for this decrease is believed to be the decrease in economic activity due to the recent economic crisis, whereas emissions have been increasing steadily in recent years as the Irish economy has recovered. The EPA estimates that non-ETS emissions in 2018/2019 will be virtually back at the 2005 levels (EPA, 2018). Assuming this, even a doubling of the carbon tax, resulting in a 4.8 per cent reduction in total emissions, will fall far short of the 2020 target.

TABLE 4.13 CHANGES IN HOUSEHOLD EMISSIONS (PER CENT)

| | €5 | €10 | €15 | €20 |
|---|---|---|---|---|
| The poorest | −1.110 | −2.223 | −3.337 | −4.453 |
| HH2 | −1.286 | −2.575 | −3.865 | −5.156 |
| HH3 | −1.361 | −2.723 | −4.086 | −5.450 |
| HH4 | −1.318 | −2.639 | −3.964 | −5.291 |
| HH5 | −1.361 | −2.725 | −4.093 | −5.464 |
| HH6 | −1.349 | −2.703 | −4.062 | −5.424 |
| HH7 | −1.403 | −2.811 | −4.222 | −5.636 |
| HH8 | −1.367 | −2.740 | −4.118 | −5.503 |
| HH9 | −1.442 | −2.889 | −4.341 | −5.797 |
| The richest | −1.353 | −2.714 | −4.082 | −5.457 |
| Economy-wide | −1.192 | −2.385 | −3.578 | −4.772 |

*Note:* *Changes in households' emissions as a result of altered consumption compositions due to an increase in carbon tax of €5, €10, €15 and €20. The bottom row shows the reductions in economy-wide emissions, i.e. it includes the effects of activity-based emissions.*

# CHAPTER 5

## Conclusions

This report investigates the potential economic impacts of an increase in the carbon tax for Ireland using an Energy Social Accounting Matrix (ESAM) multiplier analysis. This methodology allows for an investigation of direct and indirect impacts in the short term. Long-term impacts should be investigated in a dynamic setting such as that currently being developed by the ESRI in the Ireland Environment Energy Economy (I3E) model. As always, the results obtained should be interpreted with the limitations of the methodology in mind.

Our results show that the impacts on both producer and household consumer prices are relatively small. Concerning the distribution of impacts across production sectors, we find, not surprisingly, that the transport and energy sectors are most affected.

Our results concerning the impacts of an increase in carbon tax across household income deciles show higher impacts for richer households in terms of total consumer prices. When examining consumer prices of heating, we find a virtually uniform impact across income deciles. Hence, our results suggest that an increase in carbon tax will not have higher impacts on more vulnerable households and will not significantly increase fuel poverty. However, regarding the costs for households in terms of percentage of income, poorer households will feel the burden of an increased carbon tax more than richer households.

The limitations of the methodology applied here do not allow for a reliable estimation of GDP impacts of an increase in the carbon tax. Given the small impacts on both consumer and producer prices, however, we do not expect significant GDP impacts for an increase in the carbon tax of €5. The potential GDP impacts will also depend on how the government allocates the carbon tax excise receipts: potential GDP impacts of an increased carbon tax can be mitigated by other policies or reduced taxes funded by these receipts.

Although the estimated emission effects are potentially overestimated, as the methodology does not take account of general equilibrium effects, economy-wide emissions can be reduced by less than 5% in the case of a doubled carbon tax. In addition to strong economic growth, which leads to higher emissions, it is crystal clear that Ireland is far from meeting the non-ETS emission reduction targets by 2020 and 2030 even with significant increases in the carbon tax. There is a role for the government in incentivising consumers and producers further to switch to low-carbon commodities through, for example, promoting/subsidising low-carbon energy and sending a strong message of commitment to an increasing carbon tax. A clear commitment to an increasing carbon tax in addition to other policy measures is needed to bring Ireland closer to its 2020 emission targets.

# APPENDIX A: AGGREGATED VERSION OF THE IRISH SAM

| | ACT | COM | MARG | LAB | CAP | HH | ENT | PRODTAX | DIRTAX | SALTAX | GOV | SI | RoW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ACT** | | 417,954.1 | | | | | | | | | | | |
| **COM** | 240,947.3 | | 25,225.0 | | | 87,084.4 | | | | | 26,244.8 | 45,155.2 | 216,898.9 |
| **MARG** | | 25,225.0 | | | | | | | | | | | |
| **LAB** | 73,242.7 | | | | | | | | | | | | |
| **CAP** | 102,990.8 | | | | | | | | | | | | |
| **HH** | | | | 45,102.3 | | | 64,313.1 | | | | 28,076.0 | | −29,715.0 |
| **ENT** | | | | | 94,891.3 | | | | | | 13,594.9 | | |
| **PRODTAX** | 773.2 | | | | | | | | | | | | |
| **DIRTAX** | | | | 28,140.47 | 8,099.5 | | | | | | | | |
| **SALTAX** | | 17,530.4 | | | | | | | | | | | |
| **GOV** | | | | | | | | 773.2 | 36,240.0 | 17,530.4 | | | 6,274.0 |
| **SI** | | | | | | 20,692.0 | 44,173.0 | | | | −7,098.0 | | −12,611.8 |
| **RoW** | | 180,846.1 | | | | | | | | | | | |
| **TOTAL** | 417,954.1 | 641,555.6 | 25,225.0 | 73,242.7 | 102,990.8 | 107,776.4 | 108,486.1 | 773.2 | 36,240.0 | 17,530.4 | 60,817.7 | 45,155.2 | 180,846.1 |

# APPENDIX B: LISTS OF ACTIVITIES AND COMMODITIES

## TABLE B.1 ACTIVITIES BY GROUPS

| Abbreviation | Name | NACE |
|---|---|---|
| **First group** | | |
| OMN | Other Mining Products | |
| FBT | Food, Beverage and Tobacco | 10–12 |
| TEX | Textile | 13–15 |
| WWP | Wood and Wood Products | 16 |
| BFM | Basic Metal Manufacturing | 24–25 |
| HTP | High-Tech Products | 26–28 |
| EDU | Education Sector | 85 |
| **Second group** | | |
| PEA | Peat | |
| CON | Construction | 41–43 |
| PUB | Public Sector | 84 |
| **Third group** | | |
| TRE | Transportation Equipment | 29–30 |
| **Fourth group** | | |
| AGR | Agriculture | 1–3 |
| NGE | Natural Gas Extraction | |
| PET | Petroleum | |
| OTM | Furn. and Other Manufacturing | 31–32 |
| BPP | Basic Pharmaceutical Products | 21 |
| NGS | Natural Gas Supply | |
| LTS | Land Transportation | 49 |

| Abbreviation | Name | NACE |
|---|---|---|
| WTS | Water Transportation | 50 |
| ATS | Air Transportation | 51 |
| ACC | Accom. and Hotel Services | 55–56, 79 |
| TEL | Telecommunication Services | 61 |
| FSR | Financial Services | 64–66, 77 |
| RES | Real Estate Services | 68 |
| HHS | Health Sector | 86–88 |
| SER | Other Services | Remaining* |
| **Fifth group** | | |
| OIN | Other Industrial Products | 17, 18, 33 |
| CHE | Chemical Products | 20 |
| RUP | Rubber and Plastic Products | 22 |
| ONM | Other Non-metallic Products | 23 |
| WAT | Water and Sewerage | 36,37–39 |
| TRD | Trade | 45–47 |
| **Sixth group** | | |
| ELC | Electricity | |

Note: *The activities without NACE codes are further disaggregated into sectors as explained in Section 3.2.2.*
** This excludes NACE codes 5–9 (Mining, Quarrying and Extraction), 19 (Petroleum Products), and 35 (Electricity and Gas Supply).*

TABLE B.2 COMMODITIES

| | | | |
|---|---|---|---|
| AGR | Agriculture | ONM | Other Non-metallic Products |
| PEA | Peat | BFM | Basic Metal Manufacturing |
| COA | Coal | HTP | High-Tech Products |
| CRO* | Crude Oil | TRE | Transportation Equipment |
| NGE* | Natural Gas Extraction | ELC | Electricity |
| OMN* | Other Mining Products | NGS | Natural Gas Supply |
| FBT | Food, Beverage and Tobacco | WAT | Water and Sewerage |
| TEX | Textile | CON | Construction |
| WWP | Wood and Wood Products | TRD | Trade |
| OIN | Other Industrial Products | LTS | Land Transportation |
| GAL | Gasoline | WTS | Water Transportation |
| KRS | Kerosene | ATS | Air Transportation |
| FUO | Fuel-oil | ACC | Accom. and Hotel Services |
| LPG | Liquid Petroleum Gas | TEL | Telecommunication Services |
| DIE | Diesel | FSR | Financial Services |
| OPP | Other Petroleum Products | RES | Real Estate Services |
| OTM | Furn. and Other Manufacturing | PUB | Public Sector |
| CHE | Chemical Products | EDU | Education Sector |
| BPP | Basic Pharmaceutical Products | HHS | Health Sector |
| RUP | Rubber and Plastic Products | SER | Other Services |

*Note:* ** Not subject to private consumption.*

# APPENDIX C: PRICE MULTIPLIER METHODOLOGY

In practice, the price multiplier methodology utilises the accounting equilibrium principle of the SAM and tracks prices of commodities and outputs through the columns of the SAM. In order to give an overview of the methodology, an artificial SAM is presented in Table C.1 which includes two activities and three commodities.

TABLE C.1 ARTIFICIAL SAM (2 ACTIVITIES × 3 COMMODITIES)

| | A1 | A2 | C1 | C2 | C3 | F | H | E | T |
|---|---|---|---|---|---|---|---|---|---|
| A1 | | | $X11$ | $X12$ | $X13$ | | | | $X_1$ |
| A2 | | | | $X22$ | $X23$ | | | | $X_2$ |
| C1 | $Z11$ | $Z12$ | | | | | $C_1$ | $E_1$ | $Z_1$ |
| C2 | $Z21$ | $Z22$ | | | | | $C_2$ | $E_2$ | $Z_2$ |
| C3 | $Z31$ | | | | | | $C_3$ | $E_3$ | $Z_3$ |
| F | $V_1$ | $V_2$ | | | | | | | $V$ |
| H | | | | | | $V_1 + V_2$ | | | $Y$ |
| E | | | $L_1$ | $L_2$ | $L_3$ | | $S$ | | $E$ |
| T | $X_1$ | $X_2$ | $Z_1$ | $Z_2$ | $Z_3$ | $V$ | $Y$ | $E$ | |

The SAM in Table C.1 represents the Irish SAM constructed in which activities are allowed to produce multi-products. Therefore, the sub-matrix of activities and commodities in Table C.1 has not only diagonal elements that represent *primary* products of respective activities but also off-diagonal elements that represent *secondary and tertiary* products of activities. This feature comprises the basic difference with the SAM used in IFPRI (Breisinger et al., 2009), where the sub-matrix of activities and commodities has only diagonal elements. Since the multiplier analysis requires neither formal representation of price relations nor multiproduct determination decisions of activities, allowing for producing multi-products will result in prices of products produced by a single activity being equal to each other.[13] The

[13] On the other hand, in the CGE model under construction, levels of production for each product are determined by applying a revenue maximisation problem in which price differentials across products are the major determinants. For technical details, see Punt (2013, Chapter 4).

artificial SAM presented in Table C.1 is converted into a coefficient format, where each column element is divided by the column total; this SAM in coefficient form is presented in Table C.2.

By definition, for activities, the value of total output should equal the value of total inputs and the following set of equations has to hold:

$$PX_a X_a = \sum_c PQ_c \; Z_{c,a} + V_a \qquad (C1)$$

where the LHS is the total value of the output of activity *a*, that is equal to the summation of total costs of intermediate inputs and payments to factors of production. $PX_a$ stands for the price of the output of activity *a*, $PQ_c$ stands for the price of commodity *c* and $V_a$ represents payments to factors of production.

TABLE C.2 ARTIFICIAL SAM IN COEFFICIENTS (2 ACTIVITIES × 3 COMMODITIES)

| | A1 | A2 | C1 | C2 | C3 | F | H | E | T |
|---|---|---|---|---|---|---|---|---|---|
| A1 | | | $mb_{11}$ | $mb_{12}$ | $mb_{13}$ | | | | $X_1$ |
| A2 | | | | $mb_{22}$ | $mb_{23}$ | | | | $X_2$ |
| C1 | $ma_{11}$ | $ma_{12}$ | | | | | $mc_1$ | $E_1$ | $Z_1$ |
| C2 | $ma_{21}$ | $ma_{22}$ | | | | | $mc_2$ | $E_2$ | $Z_2$ |
| C3 | $ma_{31}$ | | | | | | $mc_3$ | $E_3$ | $Z_3$ |
| F | $mv_1$ | $mv_2$ | | | | | | | $V$ |
| H | | | | | | | | | $Y$ |
| E | | | $l_1$ | $l_2$ | $L_3$ | | $s$ | | $E$ |
| T | 1 | 1 | 1 | 1 | 1 | 1 | 1 | $E$ | |

The following equation should hold to ensure that the value of total available supply of each commodity equals the sum of the supply of that commodity by each production sector plus the imports:

$$PQ_c \, Z_c = \sum_a PX_a \; X_{a,c} + L_c \qquad (C2)$$

where the left-hand side (LHS) is the total value of the supply of commodity *c*, which must be equal to the supply of commodity *c* by activities and its imports. Dividing these equations by *X* and *Z*, respectively, yields the share of each component with respect to the respective column total such that:

$$\begin{aligned} PX_a &= \textstyle\sum_c PQ_c \frac{Z_{c,a}}{X_a} + \frac{V_a}{X_a} \\ PQ_c &= \textstyle\sum_a PX_a \frac{X_{a,c}}{Z_c} + \frac{L_c}{Z_c} \end{aligned} \qquad (C3)$$

Under the assumption of unitary prices which is also used in the calibration process in a standard CGE model, the fractions in equation (C.3) are simply the coefficients given in Table C.2:

$$\begin{aligned} PX_a &= \textstyle\sum_c PQ_c\, ma_{c,a} + v_a \\ PQ_c &= \textstyle\sum_a PX_a\, mb_{a,c} + l_c \end{aligned} \qquad (C4)$$

Solving these equations simultaneously for a change in levels of $v_a$ ($l_c$), which represents the share of the exogenous account in the SAM provided above, yields changes in prices of outputs (commodities). Since the Irish SAM for the year of 2014 is much more complicated than the artificial SAM provided above, the following set of equations is used in this study:

$$(1 - prodtax_a)PX_a = \sum_c PQ_c\, ma_{c,a} + \sum_f WF_{f,a}\, mv_{f,a} \qquad (C5)$$

In equation (C.5), the first term on the right-hand side (RHS) is the total cost of intermediate inputs and the second term is the total payments to the factors of production, where $WF_{f,a}$ is the price of factor *f* paid by activity *a*, and $prodtax_a$ is the production tax rate of activity *a*.

Equation (C.6) solves for commodity prices, where $st_c$ is sales tax rate on the commodity *c*. The methodology employed in this study differs from the literature on SAM-based price multipliers due to the structure of this equation, which is derived from the standard CGE literature. In reality, a commodity consumed within the domestic market is a composite of domestically produced and imported commodities, and sales taxes are collected from the value of total consumption of this composite commodity. The first term in the parentheses on the RHS of equation (C.6) is total value of consumption.[14]

$$PQ_c = \left(\sum\nolimits_a PX_a \, mb_{a,c} + l_c\right) (1 + st_c) \qquad (C6)$$

Another characteristic of this study is that the wage rate of labour in each activity is assumed to be changed at the rate of inflation. In the literature, factor prices are assumed to be constant, but this is a restrictive assumption. Although wage rates are allowed to change, the price of capital is assumed to be fixed, which is consistent with the fact that savings–investment account is assumed to be part of the exogenous account.

$$WF_{lab,a} = WF_{lab,a}^{base} \, CPI \qquad (C7)$$

As the methodology allows us to compute commodity prices, we can easily obtain changes in overall price level which is represented as consumer price index, equation (C.8), where $wgt_c$ is the weight of commodity *c* in total private consumption.

$$CPI = \sum\nolimits_c wgt_c \; PQ_c \qquad (C8)$$

By using equations (C.5) and (C.6), we can derive the following equation in matrix notation:

$$\left[1 - \frac{1 + st_c}{1 - prodtax_a} \, mb'_{a,c} \, ma'_{c,a}\right] PQ_c = mb'_{a,c} \, (1 - prodtax_a)' \, mv'_{f,a} \, WF_{f,a} + l_c \qquad (C9)$$

where the second term in the parentheses on the LHS is the price multiplier. It is evident that as sales tax rate, $st_c$, increases, the value of the first term on the LHS of (C.9) declines. For the fixed level of the RHS where all components are exogenous, commodity prices, $PQ_c$, have to increase. However, since factor prices, $WF_{f,a}$, are indexed to the overall price level, the RHS also increases, which in turn puts further pressure on commodity prices.

In this set-up, equations (C.5–C.8) solve for the new sets of producer prices of

---

[14] If we were following the standard approach in the literature, equation (C.6) would look like $(1 - st_c) \, PQ_c = \sum_a PX_a \, mb_{a,c} + l_c$

products, $PX_a$, purchaser prices of commodities, $PQ_c$, wage rates, $WF_{lab,a}$, and overall consumer price index, $CPI$ , respectively, and the set of equations constitute the SAM-based price multiplier model.

Since the constructed SAM incorporates household deciles, we can also obtain household-specific price indices by using $wgt_c^{hh}$, the weight of commodity $c$ in total private consumption of household $hh$.

$$CPI^{hh} = \sum_c wgt_c^{hh} \ PQ_c \qquad (C10)$$

In addition to this household-specific consumer price index, two different energy-related price indices are also calculated. The first, namely $CPI_{en}^{hh}$, is the price index of all energy commodities while the second, namely $CPI_{hea}^{hh}$ is the price index of all heating-related energy commodities, i.e. it excludes gasoline, diesel, LPG, and electricity demand for private transportation purposes.

# APPENDIX D: ADDITIONAL TABLES

TABLE D.1 CHANGES IN PURCHASER PRICES (PER CENT)

| | €5 | €10 | €15 | €20 |
|---|---|---|---|---|
| Agriculture | 0.067 | 0.136 | 0.207 | 0.280 |
| Peat | 0.699 | 1.407 | 2.127 | 2.858 |
| Coal | 0.946 | 1.909 | 2.891 | 3.892 |
| Natural Gas Extraction | 0.779 | 1.570 | 2.373 | 3.189 |
| Other Mining | 0.043 | 0.087 | 0.132 | 0.178 |
| Food, Beverage and Tobacco | 0.026 | 0.054 | 0.082 | 0.111 |
| Textile | 0.004 | 0.008 | 0.011 | 0.015 |
| Wood and Wood Products | 0.040 | 0.080 | 0.122 | 0.166 |
| Other Industry | 0.030 | 0.060 | 0.092 | 0.124 |
| Gasoline | 1.323 | 2.682 | 4.078 | 5.512 |
| Kerosene | 0.528 | 1.063 | 1.603 | 2.148 |
| Fuel-oil | 0.081 | 0.163 | 0.245 | 0.328 |
| LPG | 0.996 | 2.012 | 3.049 | 4.107 |
| Diesel | 1.687 | 3.432 | 5.238 | 7.108 |
| Other Petroleum Products | 0.002 | 0.004 | 0.006 | 0.008 |
| Other Manufacturing | 0.049 | 0.100 | 0.151 | 0.204 |
| Chemicals and Chemical Products | 0.017 | 0.034 | 0.052 | 0.070 |
| Basic Pharmaceutical Products | 0.014 | 0.028 | 0.043 | 0.058 |
| Rubber and Plastics | 0.029 | 0.059 | 0.089 | 0.121 |
| Other Non-metallic Mineral Products | 0.052 | 0.106 | 0.161 | 0.218 |
| Basic and Fabricated Metals | 0.032 | 0.064 | 0.097 | 0.131 |

| | €5 | €10 | €15 | €20 |
|---|---|---|---|---|
| High-Technology Production | 0.019 | 0.038 | 0.057 | 0.077 |
| Transportation Equipment | 0.002 | 0.004 | 0.007 | 0.009 |
| Electricity | 0.167 | 0.337 | 0.510 | 0.685 |
| Natural Gas Supply | 0.324 | 0.653 | 0.988 | 1.328 |
| Water and Sewerage | 0.058 | 0.118 | 0.180 | 0.244 |
| Construction | 0.063 | 0.129 | 0.196 | 0.265 |
| Trade Activities | 0.037 | 0.074 | 0.113 | 0.153 |
| Land Transportation Services | 0.251 | 0.509 | 0.777 | 1.054 |
| Water Transportation Services | 0.257 | 0.523 | 0.798 | 1.082 |
| Air Transportation Services | 0.224 | 0.454 | 0.689 | 0.930 |
| Accommodation and Related Services | 0.067 | 0.136 | 0.207 | 0.281 |
| Telecommunication | 0.032 | 0.065 | 0.099 | 0.134 |
| Financial Services | 0.014 | 0.028 | 0.042 | 0.057 |
| Real Estate Services | 0.010 | 0.020 | 0.030 | 0.040 |
| Public Administration | 0.088 | 0.178 | 0.271 | 0.367 |
| Education Services | 0.100 | 0.202 | 0.307 | 0.416 |
| Human, Health and Social Work | 0.091 | 0.184 | 0.280 | 0.379 |
| Services | 0.030 | 0.061 | 0.094 | 0.127 |

TABLE D.2 CHANGES IN PRODUCER PRICES (PER CENT)

| | €5 | €10 | €15 | €20 |
|---|---|---|---|---|
| Agriculture | 0.088 | 0.179 | 0.273 | 0.371 |
| Peat | 0.048 | 0.097 | 0.148 | 0.200 |
| Natural Gas Extraction | 0.130 | 0.263 | 0.398 | 0.536 |
| Other Mining | 0.053 | 0.107 | 0.163 | 0.221 |
| Food, Beverage and Tobacco | 0.044 | 0.088 | 0.134 | 0.182 |
| Textile | 0.040 | 0.081 | 0.123 | 0.167 |
| Wood and Wood Products | 0.066 | 0.135 | 0.205 | 0.278 |
| Other Industry | 0.054 | 0.110 | 0.168 | 0.227 |
| Petroleum | 0.032 | 0.066 | 0.100 | 0.135 |
| Other Manufacturing | 0.076 | 0.154 | 0.233 | 0.314 |
| Chemicals and Chemical Products | 0.030 | 0.060 | 0.091 | 0.123 |
| Basic Pharmaceutical Products | 0.017 | 0.034 | 0.051 | 0.069 |
| Rubber and Plastics | 0.061 | 0.124 | 0.189 | 0.256 |
| Other Non-metallic Mineral Products | 0.082 | 0.166 | 0.253 | 0.343 |
| Basic and Fabricated Metals | 0.071 | 0.144 | 0.219 | 0.296 |
| High-Technology Production | 0.041 | 0.082 | 0.125 | 0.169 |
| Transportation Equipment | 0.051 | 0.103 | 0.157 | 0.213 |
| Electricity | 0.138 | 0.280 | 0.424 | 0.571 |
| Natural Gas Supply | 0.345 | 0.696 | 1.052 | 1.414 |
| Water and Sewerage | 0.059 | 0.119 | 0.182 | 0.246 |
| Construction | 0.063 | 0.129 | 0.196 | 0.265 |
| Trade Activities | 0.053 | 0.108 | 0.165 | 0.223 |
| Land Transportation Services | 0.261 | 0.531 | 0.809 | 1.098 |

| | €5 | €10 | €15 | €20 |
|---|---|---|---|---|
| Water Transportation Services | 0.282 | 0.573 | 0.875 | 1.186 |
| Air Transportation Services | 0.263 | 0.533 | 0.809 | 1.092 |
| Accommodation and Related Services | 0.078 | 0.158 | 0.241 | 0.326 |
| Telecommunication | 0.043 | 0.086 | 0.132 | 0.178 |
| Financial Services | 0.029 | 0.060 | 0.091 | 0.123 |
| Real Estate Services | 0.010 | 0.019 | 0.029 | 0.040 |
| Public Administration | 0.088 | 0.178 | 0.272 | 0.368 |
| Education Services | 0.100 | 0.202 | 0.307 | 0.416 |
| Human, Health and Social Work | 0.091 | 0.184 | 0.280 | 0.379 |
| Services | 0.035 | 0.072 | 0.110 | 0.148 |

TABLE D.3 CHANGES IN ACTIVITY-BASED EMISSIONS (PER CENT)

| | €5 | €10 | €15 | €20 |
|---|---|---|---|---|
| Agriculture | −1.948 | −3.897 | −5.849 | −7.802 |
| Peat | −2.371 | −4.724 | −7.059 | −9.375 |
| Natural Gas Extraction | −0.972 | −1.941 | −2.908 | −3.872 |
| Other Mining | −0.629 | −1.262 | −1.901 | −2.546 |
| Food, Beverage and Tobacco | −0.977 | −1.953 | −2.928 | −3.902 |
| Textile | −0.460 | −0.923 | −1.388 | −1.856 |
| Wood and Wood Products | −0.318 | −0.638 | −0.961 | −1.285 |
| Other Industry | −0.628 | −1.256 | −1.885 | −2.516 |
| Petroleum | −1.071 | −2.140 | −3.207 | −4.271 |
| Other Manufacturing | −1.324 | −2.642 | −3.952 | −5.255 |
| Chemicals and Chemical Products | −1.091 | −2.180 | −3.266 | −4.350 |
| Basic Pharmaceutical Products | −0.398 | −0.799 | −1.203 | −1.610 |
| Rubber and Plastics | −0.861 | −1.723 | −2.586 | −3.451 |
| Other Non-metallic Mineral Products | −1.241 | −2.478 | −3.709 | −4.936 |
| Basic and Fabricated Metals | −0.745 | −1.491 | −2.237 | −2.983 |
| High-Technology Production | −1.012 | −2.027 | −3.044 | −4.063 |
| Transportation Equipment | −0.323 | −0.648 | −0.975 | −1.304 |
| Electricity | −0.719 | −1.439 | −2.158 | −2.878 |
| Natural Gas Supply | −0.835 | −1.668 | −2.496 | −3.322 |
| Water and Sewerage | −1.067 | −2.132 | −3.196 | −4.258 |
| Construction | −1.525 | −3.056 | −4.594 | −6.138 |
| Trade Activities | −1.150 | −2.299 | −3.448 | −4.597 |
| Land Transportation Services | −2.460 | −4.898 | −7.311 | −9.702 |

| | €5 | €10 | €15 | €20 |
|---|---|---|---|---|
| Water Transportation Services | −2.496 | −4.966 | −7.410 | −9.829 |
| Air Transportation Services | −1.077 | −2.154 | −3.232 | −4.311 |
| Accommodation and Related Services | −0.708 | −1.426 | −2.155 | −2.893 |
| Telecommunication | −0.448 | −0.901 | −1.361 | −1.827 |
| Financial Services | −0.580 | −1.169 | −1.767 | −2.374 |
| Real Estate Services | −0.400 | −0.804 | −1.214 | −1.629 |
| Public Administration | −0.868 | −1.744 | −2.627 | −3.517 |
| Education Services | −0.653 | −1.310 | −1.970 | −2.634 |
| Human, Health and Social Work | −0.502 | −1.009 | −1.524 | −2.045 |
| Services | −1.118 | −2.249 | −3.394 | −4.552 |

# APPENDIX E: NESTED STRUCTURES OF CONSUMPTION AND PRODUCTION

## FIGURE E.1 COMPOSITE PRIVATE CONSUMPTION

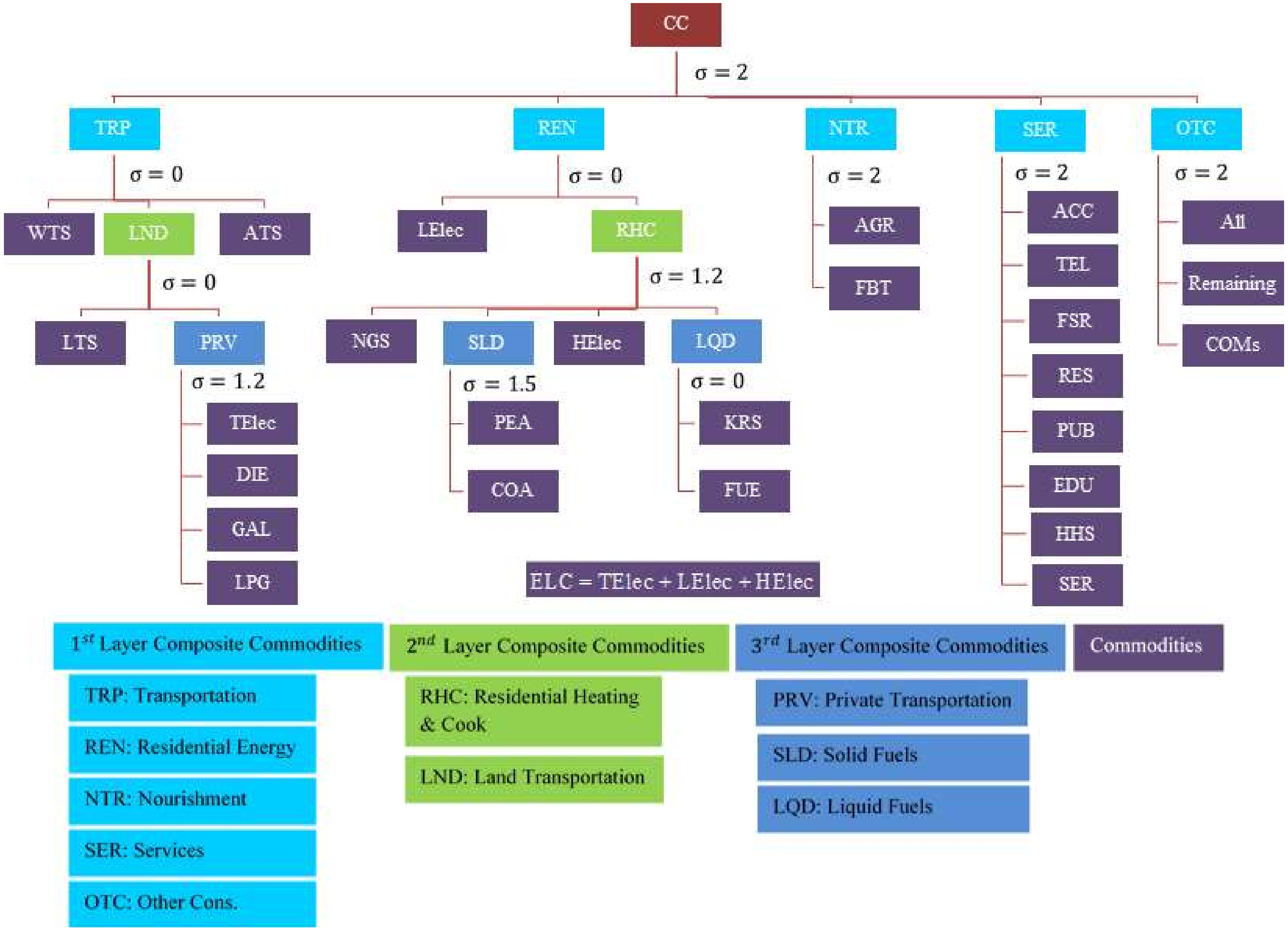


**FIGURE E.2 PRODUCTION, EXCEPT ELECTRICITY PRODUCTION**

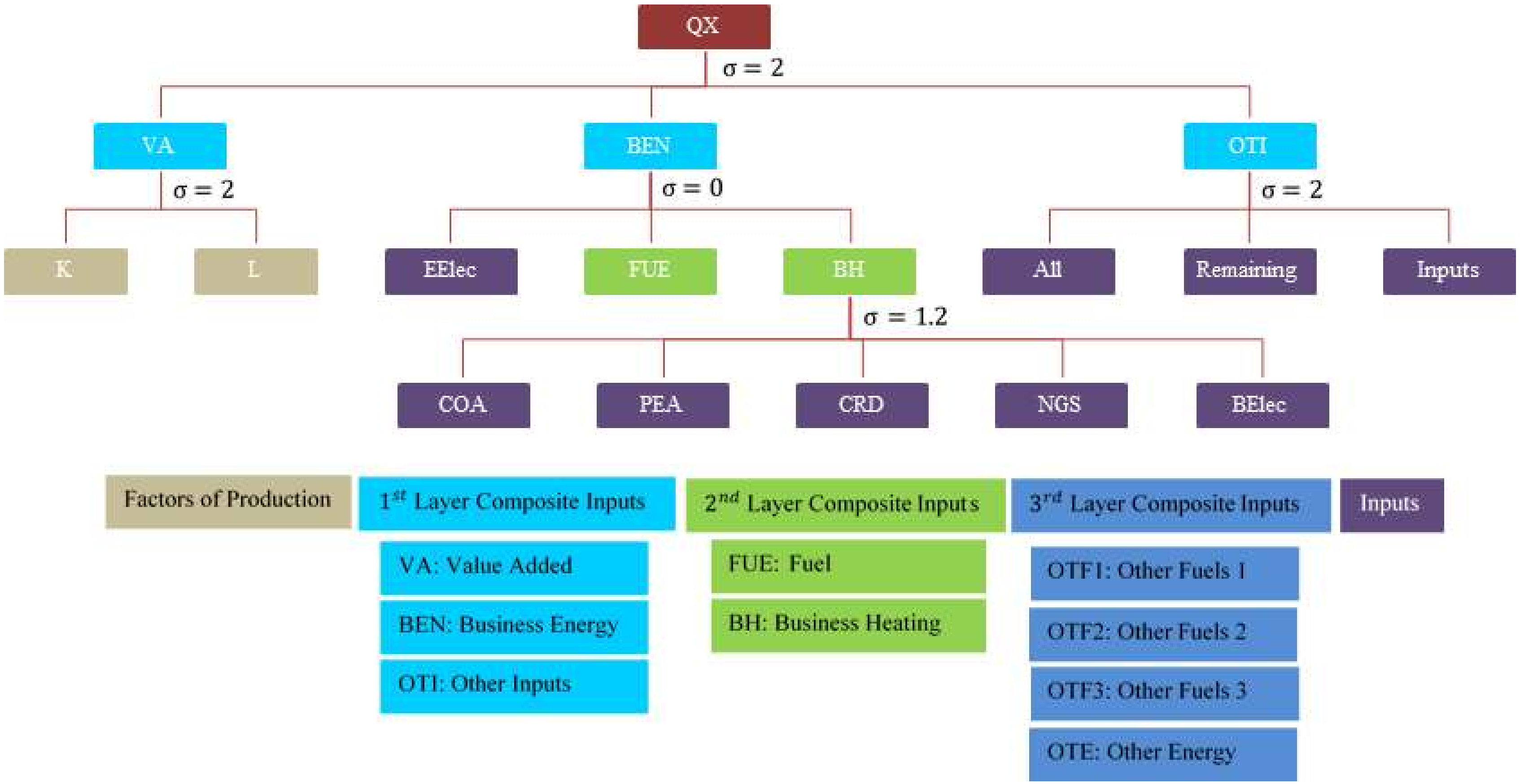


**FIGURE E.3 FUEL CONSUMPTION BY GROUP OF ACTIVITIES**

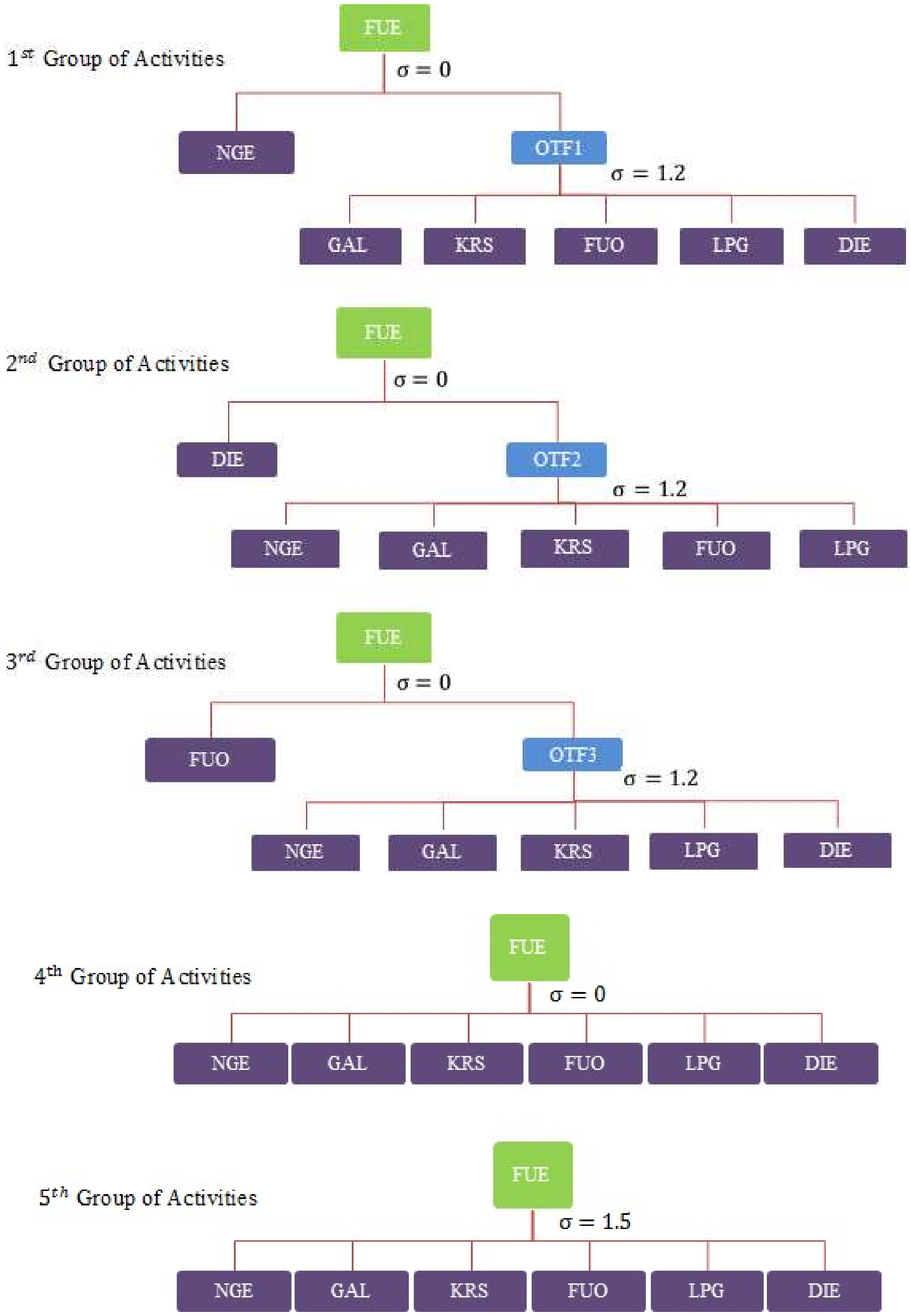
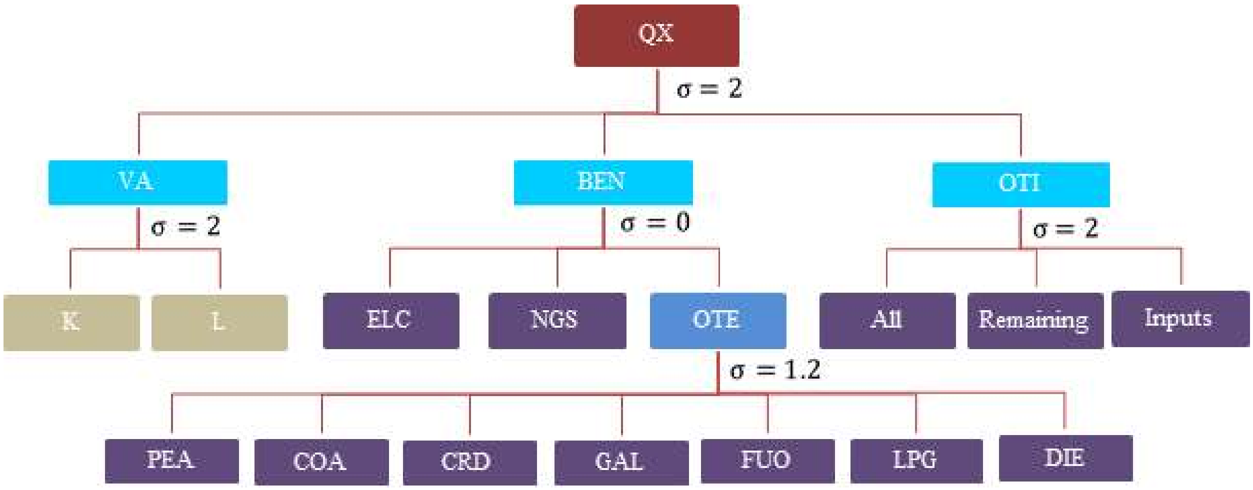


**FIGURE E.4 ELECTRICITY PRODUCTION**



# REFERENCES


Bergin, A., J. FitzGerald, and I. Kearney (2004). *The macro-economic effects of using fiscal instruments to reduce greenhouse gas emissions*, Technical Report, Dublin: The Economic and Social Research Institute. https://www.esri.ie/publications/the-macro-economic-effects-of-using-fiscal-instruments-to-reduce-greenhouse-gas-emissions-2001-eep-ds8-m1-final-report-prepared-for-the-environmental-protection-agency/

Breisinger, C., M. Thomas, and J. Thurlow (2009). *Social accounting matrices and multiplier analysis: an introduction with exercises*, Technical Report No. 5, Washington, DC: International Food Policy Research Institute (IFPRI). https://ideas.repec.org/p/fpr/fsprac/5.html

Chapa, J. and A. Ortega (2017). 'Carbon tax effects on the poor: A SAM-based approach', *Environmental Research Letters*, Vol. 12, No. 9, doi: 10.1088/1748-9326/aa80ed.

Choi, J.-K., B.R. Bakshi, and T. Haab (2010). 'Effects of a carbon price in the U.S. on economic sectors, resource use, and emissions: an input–output approach', *Energy Policy*, Vol. 38, No. 7, pp. 3527–3536. doi: 10.1016/j.enpol.2010.02.029

Conefrey, T., J.D. FitzGerald, L.M. Valeri, and R.S.J. Tol (2013). 'The impact of a carbon tax on economic growth and carbon dioxide emissions in Ireland', *Journal of Environmental Planning and Management*, Vol. 56, No. 7, pp. 934–952.

Cronin, J.A., D. Fullerton, and S.E. Sexton (2017). *Vertical and horizontal redistributions from a carbon tax and rebate*, Working Paper No. 23250, Cambridge, MA: National Bureau of Economic Research.

de Koning, A., R. Heijungs, and A. Tukker (2011). *A new environmental accounting framework using externality data and input-output tools for policy analysis*, Technical Report, Exiopol. https://www.exiobase.eu/index.php/publications/documentation/8-technical-report-exiobase/file.

Desmond, M., P. O'Brien, and F. McGovern (2017). *A summary of the state of knowledge on climate change impacts for Ireland*, Technical Report No. 223, Johnstown Castle, Co. Wexford: Environmental Protection Agency. http://www.epa.ie/pubs/reports/research/climate/research223.html

Diamond, J.W. and G.R. Zodrow (2018). *The effects of carbon tax policies on the US Economy and the welfare of households*, Independent Report, New York: Columbia SIPA Center on Global Energy Policy.

EPA (2018). *Ireland's greenhouse gas emissions projections 2017–2035*, Johnstown Castle, Co. Wexford: Environmental Protection Agency. http://www.epa.ie/pubs/reports/air/airemissions/ghgprojections2017-2035/

Eurostat (2008). *Eurostat manual of supply, use and input–output tables*, Luxembourg: Eurostat.

Eurostat (2013). *European system of accounts (ESA 2010)*, Luxembourg: Eurostat.

Feuerbacher, A. (2014). *Development of a 2007 Social Accounting Matrix (SAM) for Bhutan and multiplier-based policy experiments*, MSc thesis, Humboldt-Universität zu Berlin.

FitzGerald, J., J. Hore, and I. Kearney (2002). *A model for forecasting energy demand and greenhouse gas emissions in Ireland*, Paper WP146, Dublin: The Economic and Social Research Institute.

Grover, D., G. Shreedhar, and D. Zenghelis (2016). *The competitiveness impact of a UK carbon price: what do the data say?* Policy Paper, Leeds and London: ESRC Centre for Climate Change Economics and Policy.

Hassett, K.A., A. Mathur, A., and G.E. Metcalf (2009). 'The incidence of a U.S. carbon tax: a lifetime and regional analysis', *Energy Journal*, Vol. 30, No. 2, pp. 155–177.

IPCC (2014). *Climate Change 2014: synthesis report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (R.K. Pachauri and L.A. Meyer, eds), Geneva: Intergovernmental Panel on Climate Change.

Lyons, S., A. Pentecost, and R.S.J. Tol (2012). Socioeconomic distribution of emissions and resource use in Ireland. *Journal of Environmental Management*, Vol. 112, pp. 186–198.

Parra, J.C. and Q. Wodon (2008). *Comparing the impact of food and energy price shocks on consumers: a social accounting matrix analysis for Ghana*, Policy Research Working Paper 4741, Washington, DC: The World Bank. http://hdl.handle.net/10986/6945

Perese, K. (2010). *Input–output model analysis: pricing carbon dioxide emissions*, Working Paper 2010-04, Washington, DC: Congressional Budget Office.

Punt, C. (2013). *Modelling multi-product industries in computable general equilibrium (CGE) models*, PhD thesis, Stellenbosch University.

Pyatt, G. and J.I. Round (1979). 'Accounting and fixed price multipliers in a social accounting matrix framework', *Economic Journal*, Vol. 89, No. 356, pp. 850–873.

Rausch, S., G.E. Metcalf, and J.M. Reilly (2011). 'Distributional impacts of carbon pricing: a general equilibrium approach with micro-data for households', *Energy Economics*, Vol. 33, S1, pp. S20–S33.

Roland-Holst, D.W. and F. Sancho (1995). 'Modeling prices in a SAM structure', *Review of Economics and Statistics*, Vol. 77, No. 2, pp. 361–371.

Round, J. (2003). 'Social accounting matrices and SAM-based multiplier analysis', in F. Bourguignon and L.A. Pereira da Silva (eds), *The impact of economic policies on poverty and income distribution: evaluation techniques and tools*, Washington, DC: The World Bank.

Sigwele, H.K. (2007). *The effects of international trade liberalization on food security and competitiveness in the agricultural sector of Botswana*, PhD thesis, University of Pretoria.

Sustainable Energy Authority of Ireland (2013). *Energy in the residential sector*, Technical Report, Dublin: SEAI. https://www.seai.ie/resources/publications/Energy-in-the-Residential-Sector-2013.pdf

Tlhalefang, J. and O. Galebotswe (2013). Welfare effects of higher energy and food prices in Botswana: a SAM price multiplier analysis, *Botswana Journal of Economics*, Vol. 11, No. 15, pp. 21–31.

UN (1999). *Handbook of input–output table compilation and analysis*, New York: United Nations.

Verde, S.F. and R.S.J. Tol (2009). 'The distributional impact of a carbon tax in Ireland', *Economic and Social Review*, Vol. 40, No. 3, pp. 317–338.

Williams, R., H. Gordon, D. Burtraw, J. Carbone, and R.D. Morgenstern (2015). 'The initial incidence of a carbon tax across income groups', *National Tax Journal*, Vol. 68, No. 1, pp. 195–214.

Wissema, W. and R. Dellink (2007). 'AGE analysis of the impact of a carbon energy tax on the Irish economy', *Ecological Economics*, Vol. 61, No. 4, pp. 671–683.

Whitaker Square,
Sir John Rogerson's Quay,
Dublin 2
Telephone **+353 1 863 2000**
Email **admin@esri.ie**
Web **www.esri.ie**
Twitter **@ESRIDublin**
ISBN **978-0-7070-0470-9**

ECONOMIC & SOCIAL
RESEARCH INSTITUTE